

MIT Security Studies Conference Series



The Future of the Trident Force

Enabling Access in Access-Constrained Environments

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE MAY 2002		2. REPORT TYPE		3. DATES COVERED 00-05-2002 to 00-05-2002	
4. TITLE AND SUBTITLE The Future of the Trident Force. Enabling Access in Access-Constrained Environments				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Massachusetts Institute of Technology, Security Studies Program, BG E38, 6th Floor, Cambridge, MA, 02139				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES The original document contains color images.					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES 58	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

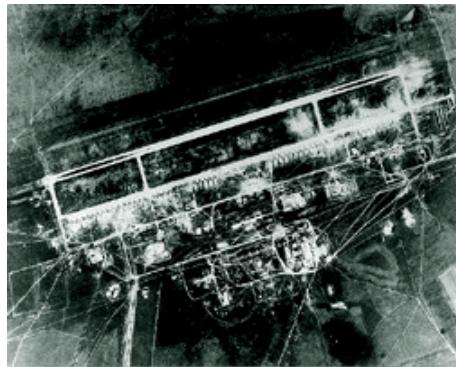
The Future of the Trident Force

Enabling Access in Access-Constrained Environments

Owen R. Coté, Jr.
MIT Security Studies Program
May 2002

This report is the product of an M.I.T. Security Studies Program Conference organized by Owen Cote, Associate Director of the Security Studies Program. Held on 7-8 November 2001 in Cambridge, Massachusetts, the conference looked at the future of the U.S. Navy's Trident submarine force, with a specific focus on future roles for converted Trident SSGNs. It is the fourth in a series of conferences held in honor of the late Vice Admiral Levering Smith, USN, the technical director of the Navy's Fleet Ballistic Missile program during the development of Polaris, and from 1965 to 1977, its director.

The author would like to thank those who participated in the conference; especially Kristen Cashin, Magdalena Rieb, and Harlene Miller for their administrative assistance, and Brandi Sladek for designing and producing the conference report. The author would also like to thank the Electric Boat Company for its help in defraying the costs of the conference. The views expressed within this report are the author's alone and should not be attributed to any other conference participants. The report is also available online at <http://web.mit.edu/ssp>.



Military satellites have been imaging fixed targets from space for more than 40 years. The technology required to locate airfields and to determine whether and by whom they are being used is therefore relatively mature. This is reflected in the fact that commercial satellite imagery is now widely available that is much better in every respect than earlier military satellite imagery.



The first Trident SSBN, USS Ohio, transformed the Cold War nuclear deterrence mission when it joined the fleet in 1981. When it rejoins the fleet as an SSGN, it will transform how the U.S. Navy projects conventional power in the new, access-constrained security environment.

Executive Summary

The decision to convert four Trident submarines to SSGNs establishes a future for the Trident force beyond the nuclear deterrence mission. SSGNs will provide unique capabilities in at least four mission areas. First, they will provide an absolutely covert means in peacetime of holding high value targets at risk of immediate attack for as long as national decision makers deem necessary. Second, early in a conflict, they will be one of the few power projection assets that can operate in the face of opposing anti-access forces, while at the same time being one of the primary means of eliminating or reducing those access denial forces. Third, having helped create operational sanctuaries in the littoral environment for joint forces on the surface and in the air, SSGNs will retain a key role as a continuing source of the most time critical fires against high value targets. Fourth, across the full spectrum of operations from peacetime to high intensity conflict, SSGNs will provide the only means of covertly delivering, supporting with time critical fires, and recovering special operations forces.

In support of these diverse roles, four additional payloads should be added to the baseline SSGN conversion involving Tomahawk cruise missiles and a special forces delivery and recovery capability. First, SSGNs should be given a Tactical Ballistic Missile (TBM) capability. Existing TBMs of roughly the same size as Tomahawk can deliver a variety of unitary and sub-munition payloads as deep as 500 kilometers faster than any other existing weapon, and for equal or less cost compared to such air-delivered, standoff weapons as JASSM, SLAM-ER, AGM-142/130, and JSOW-B/C. Such a time critical, deep strike capability against high value, mobile targets would complement Tactical Tomahawk's deep strike capability against high value, fixed targets.

Second, SSGNs should be provided an organic Unmanned Aerial Vehicle (UAV) capability. The UAV should be cheap enough for one way missions, small and slow enough to remain covert when in use, of relatively high endurance, and should support modular payloads chosen specifically to support SSGNs only in those missions when it will likely be operating alone. For example, in advance of a strike where surprise is paramount, UAVs with simple electro/optical (EO) cameras and laser rangefinders could be deployed to confirm the presence of, monitor, and, if necessary, geolocate targets initially discovered by space-based assets with low revisit rates. Alternatively, early in a conflict in an access-constrained environment, SSGNs could deploy triplets of UAVs with small, passive, broadband RF arrays to form time-difference-of-arrival (TDOA) targeting networks able to quickly identify and geolocate mobile SAM engagement radars.

Third, SSGNs should be given an Unmanned Underwater Vehicle (UUV) that can deliver and recover submerged payloads from and to the submarine. Such a capability would support the covert deployment, operation, and recovery of undersea sensing and communication grids key to the quick elimination of future submarine and mine warfare threats. It could also support the distributed, close in launch of fire support weapons like NetFires, and of the small UAVs described above.

Fourth, for those scenarios when SSGNs are operating as part of a joint force, they should be given the capability to plug into and exploit the networks that are being

developed to provide joint forces a common operational picture, and to support strike operations against mobile/time critical targets. To this end the submarine force must influence the design tradeoffs that determine connectivity requirements in these networks. In this effort, the submarine force should note that SSGN's primary role as a source of close in, time critical fires will make its connectivity requirements resemble those of a combat aircraft being sent targeting information while enroute to its target, as in Operation Enduring Freedom. Because SSGN can deploy weapons that are relatively immune to opposing air defenses, because SSGN can deploy those weapons continuously within range of their targets, and finally, because SSGN-launched weapons will impact their targets so quickly after launch, mission planning for individual strikes should rarely require more than the provision of a GPS coordinate, a specific weapon payload, and a time on target.

Adding these four capabilities to the baseline SSGN conversion program will deepen the impact of an already transformational program. In particular, they will allow the submarine force to fully exploit the promise of the only platform that can provide a continuous presence in the most access-constrained environments, and which can quickly deliver a large payload of weapons against which there is little or no defense. This is the impact that SSBNs had during the Cold War, and it is the impact that SSGN can have in a future era when mobile targets can be found with the same precision as fixed targets, and individual conventional weapons can deliver precision effects that once required massed conventional bombing raids.

In focusing on power projection in an access-constrained environment, and in particular on time critical strikes to destroy rather than merely suppress advanced, mobile, radar-guided SAM systems, this report focuses on the mission area where SSGN will have its greatest near term impact in the larger, joint arena. The payloads and sensors to support this mission are already developed for the most part, and could be available when SSGN initially deploys in 2007. The challenge will be to establish the value of SSGN in a mission area where submarines have no traditional roles.

A large payload submarine like SSGN will also have many other potential uses in the joint arena, ranging from fire support for lighter, air-delivered ground forces to boost phase missile defense, and the report's silence on SSGN's role in those and other joint mission areas is a reflection of the inherent limitations of the author rather than of SSGN. Also, there is much less discussion of SSGN's role in undersea warfare, where it will have enormous potential, but where the submarine force is much better prepared from past experience to exploit that potential.



Access denial weapons must be provoked into revealing themselves and then quickly attacked and destroyed, because when they are hiding they cannot be detected, and when they are merely suppressed or eluded, they remain as a threat-in-being.



Introduction to the Access-Constrained Security Environment

There has been much talk of transformation in the Defense Department in the past year. Some complain about transformation foregone when they see few major weapon system cancellations, while others see transformation in every significant improvement to a current system. Clearly transformation is a term whose meaning has become extremely malleable. Innovation is another such term, as is revolution, and they form a triad of concepts that nobody opposes but which mean all things to all people.

To focus the discussion that follows, one can think of military transformation as change that results in a major shift in the division of labor amongst the major platforms or combat arms deployed by the military services, or the creation of wholly new platforms or combat arms. Transformation can be driven by changes in the external security environment or it can result from opportunities for innovation created by new technology. Usually, transformation results from a complicated interplay between these two forces. The Trident SSBN to SSGN conversion program is such a transformation.

One of the main changes in the external security environment since the end of the Cold War has been the shift from a continental focus where forces are deployed in peacetime near where they expect to fight, to a more expeditionary focus where forces must deploy to their battlefields from the United States or from the sea. Adaptation to this new demand is complicated by both political and technological trends that limit the military's access to the regions where it will most likely need to project power. Formal alliances dating from the Cold War, and the assured access to regional bases that they provided, have declined in relative importance compared to more informal coalitions formed after a conflict has already begun. In these coalitions, U.S. forces must generally negotiate access to regional bases on the fly, and the access that results is therefore less predictable in advance of a conflict than in the past.

At the same time, technological trends are making fixed targets more and more vulnerable to attack. In particular, when potential opponents follow the United States in marrying precision guidance technologies to cruise and ballistic missiles they will be able to hold fixed bases within a radius of up to a 1000 miles at risk of conventional attack by cruise and ballistic missiles against which defense is extremely difficult.

These access constraints place a premium on forces that rely less on such bases, but the force structure that the U.S. military built to prosecute the Cold War placed a premium on forces that depended on such access. The challenge of developing better means of projecting power under these circumstances will require transformation because it will force the services to rely more on forces that project power from the sea or from more distant bases. Toward this end, Trident SSGNs will transform the Navy's and the submarine force's ability to forward deploy payload in hostile, access-constrained environments.

A second major transformational challenge results from an opportunity rather than a threat. Today, when the United States conducts strike operations, it focuses on attacking fixed targets because those are the targets that it can find.

But attacking fixed targets usually represents, at best, an indirect approach to destroying an opponent's forces, especially when they are deployed in the field, which is why strike operations have often focused more on so-called "strategic bombing" operations in which targets are chosen more for their anticipated affect on the opponent's will to fight, rather than his ability to fight. Against a determined opponent, such operations can result in the expenditure of vast tonnages of ordnance in "level of effort" operations over protracted periods with little military effect.

The U.S. military has an opportunity to embrace the information technology that could allow it to find, identify, track, and target mobile targets, and marry that technology to the precision weapon revolution that it has already embraced. The full exploitation of these technologies would lead within 10-20 years to a dramatically increased ability to disarm an opponent from a distance by destroying his forces in the field. It could also lead to a power projection posture in which the principle of the economy of force was able to reassert itself, because weapons with high probabilities of kill would be used only against targets whose destruction leads to immediate, direct, and cumulative reductions in the opponent's military capabilities. This would reduce or eliminate the ability of even a determined opponent to withstand attack by U.S. forces, because it would directly effect his ability rather than just his will to fight.

As with the challenges posed by access constraints, developing an ability to attack mobile targets will require transformation because the marriage between mobile target sensor networks and precision weapons cannot be fully exploited unless the targets found by the sensor network are attacked within minutes. But developing this ability to perform reactive, "time critical" strikes will be difficult because today's forces and their doctrines for operation are optimized for massed, pre-planned attacks against fixed targets in which time is not of the essence. Trident SSGNs will transform the Navy's and the submarine force's time critical strike posture by marrying in one platform the forward persistence of an SSN with the standoff missile firepower of an entire Battle Group.

Finally, the threat of constrained access and the opportunity to find and attack mobile targets interact with each other, because one challenge cannot be solved in isolation from the other. Constraints on access will generally limit the overall size of the forces available to military commanders at the outset of a conflict, and specifically limit the deployment of sensor and time critical targeting networks for attacking mobile targets that must operate within line-of-sight of the enemy. But at the same time, such networks will be necessary for dealing with the military anti-access threats because anti-access forces are themselves a subset of the more general mobile target problem. And in addition, dealing with the anti-access problem will require that the U.S. military also deploy forces sufficient to threaten major targets the enemy values highly, because only such attacks will cause the opponent to order its anti-access forces to come out and fight.

This is because the systems used to deny or limit the access of U.S. forces can evade detection or attack if they are not forced to operate aggressively against U.S. forces. Like most mobile targets, they generally expose themselves to detection and attack only when they press home engagements. This will be

especially true early in a conflict when it is difficult for U.S. forces to infest the battlefield with persistent sensors and weapons. Thus, the leading edge of U.S. power projection efforts cannot simply be a small, silver bullet force that assumes the adversary's access denial forces will cooperate in their own destruction by pressing home engagements against it, as, for example, the Iraqi air defenses did on the first night of Desert Storm. Instead, the leading edge force must be designed on the assumption that it faces a non-cooperative opponent; one that will be opportunistic and selective in its use of its access denial forces, as were the Serbian air defenses all throughout Allied Force.

To destroy a non-cooperative access denial force, the leading edge access enabling force must be large enough to mount attacks against at least a subset of the targets of highest military and political value to the opponent. Otherwise, the opponent will withhold his anti-access forces and employ them as a threat in being. During Allied Force, one such target set was the Serbian Army deployed along the border with and inside Kosovo. As long as the allies refrained from or were unable to mount decisive attacks against this force in the field, the Serbians refrained from fully committing their mobile air defenses to battle with allied aircraft, and as long as these air defenses refrained from pressing home engagements, they proved impossible for allied forces to destroy.

Such a threat in being can significantly reduce the power projection capabilities of even a vastly superior force. It does this primarily by forcing the superior force to escort all forces through contested sea and air space. The need to provide escorts makes the size of the escort force a determining factor in the pace and intensity of operations, and given that these assets are often scarce, this can become a major constraint. The need to provide escorts also leads planners to form strike packages in the air and convoys at sea. This allows for the most efficient use of scarce escorts, but makes the presence of U.S. forces in contested areas intermittent rather than continuous, and also creates the need for a significant amount of mission planning before entering contested areas, thereby reducing reaction time.

The key to defeating opposing anti-access forces will therefore depend on platforms which can deploy large weapon payloads into contested areas on a continuous basis without need for regional bases, and sensor networks that can find, identify, and target anti-access forces whenever they move at high speed, shoot a weapon, or operate an active sensor for even brief periods. The combination of these two capabilities in a leading edge, access enabling force will threaten an opponent's vital interests, while at the same time it will threaten the opponent's access denial forces with immediate destruction if they expose themselves in an attempt to defend those vital interests. Trident SSGNs, with a combination of organically deployed sensors and the connectivity to link into joint and national sensor networks, will meet these needs better than any other platform.

Certainly, the leading edge, access enabling force will be a combined arms team. One purpose of this report is to describe in some detail how constraints on access will likely affect the different elements of the U.S. military's force structure that might play on this team. Another purpose is to review the specific technical opportunities for developing sensing, targeting, and time critical strike networks

for use against access denial forces. Finally, the report will show why forward deployed SSGNs will of necessity be a main component of the access enabling team and how that team might operate in different scenarios. According to the definition of transformation used above, the reader will see that an SSGN force enjoying the same degree of connectivity as a strike fighter, and armed with cruise missiles, tactical ballistic missiles (TBMs), and both unmanned aerial and underwater vehicles (UAVs and UUVs), will help transform the U.S. military's ability to project power quickly and decisively in an access constrained environment.



Even when an opponent is very weak militarily, as has been the case in Operation Enduring Freedom, political constraints on access can limit U.S. power projection to those platforms that can operate from the sea, or from distant land bases. In the future, military constraints on access will likely reinforce this demand.

Establishing A Secure Base

All strike warfare missions begin at a base where weapon-carrying platforms are maintained, and in some cases, launched and recovered. For the United States, which is always projecting power far away from its own shores, such bases, with rare exceptions, are not located on sovereign territory. Thus, power projection traditionally requires the establishment of a secure base, or actually several secure bases, within the theater of operations on some other country's or countries' sovereign territory.

Security is here defined in both political and military terms. The security of a base in political terms is measured according to the degree of access to the base that is guaranteed by the host nation. The military security of a base is measured in terms either of the ability of the base itself to survive attack, or of the survivability of the platforms it supports when they are deployed there. In assessing the degree of guaranteed political access, the main variation occurs between land and sea basing, while in assessing the degree of base survivability, the main variation in the near term will be between fixed and mobile bases, while in the longer term, the tradeoff is likely to be between all surface bases and undersea or space bases.

Political Constraints on Access to Bases Ashore

The political constraints on access to foreign bases affect land and sea-based forces differently. The main difference is not that one mode needs overseas bases while the other does not, but that land bases launch weapons while naval bases do not. This distinction makes naval bases less threatening to the host nation, not just because it makes those bases less of a target, though it may certainly have that effect as well, but because it separates the host nation politically from the actions taken by the U.S. naval forces that use those bases.

This is a function of the range and endurance of naval platforms, which go to sea for months at a time, and often operate literally around the world from their bases. Certainly, when ships go to sea, they are supported by an extensive train of supporting vessels, which replenish supplies of fuel oil, dry cargo, and, in the midst of a conflict, ammunition. But this umbilical connecting deployed navy combatants to the shore is largely indistinguishable from normal commercial activity, and is in fact often conducted by civilian-crewed ships that are essentially indistinguishable from their purely commercial counterparts. Thus, for example, when the U.S. Navy first began regular Indian Ocean battle group deployments in the late 1970s after the fall of the Shah, its oiler and stores ships were able to obtain needed supplies from a variety of countries along the Indian Ocean littoral, none of which were willing to provide any level of base access ashore to land-based American forces.

This distinction is reflected in actual legal arrangements. For example, everywhere the United States has access to overseas bases for land-based forces it has an accompanying set of agreements with the host nation about how those forces will or will not be used. Thus, in a recent example, after the Taiwan straits crisis of 1997, the United States apparently sought to negotiate with Japan over

future guarantees that bases on its territory which were not available in 1997, would be in the future under similar circumstances. No such negotiations were necessary regarding the use of Yokosuka and other U.S. Navy facilities in Japan, even though the primary U.S. military response to the 1997 crisis was naval, and involved forces homeported in Japan. Likewise, land-based forces have experienced significant constraints on the use of bases in the Persian Gulf region during Operation Enduring Freedom, while sea-based forces have enjoyed unlimited access to naval facilities in the same region.

Certainly, this asymmetry in favor of sea basing does not come without its costs, and sea-based forces may be less cost effective than analogous land-based forces in those cases where the latter have assured access to local, prepared bases in advance of a conflict. But as has become eminently clear, this level of access will be much less common in the future security environment than it was during the Cold War.

Access for land-based forces can be constrained in both time and scope. For example, a country might deny American strike aircraft based there permission to bomb a neighbor, but allow aircraft flying supporting missions to operate, as has been routine in the Persian Gulf region since Desert Storm. Similarly, a country that had allowed the United States to pre-position war material to support rapid deployment of land-based forces in a crisis will be likely to support such a deployment only under a particular set of circumstances, against a particular opponent. Also, a country might or might not allow a U.S. force to stage through its territory or its air space on the way to another country's bases, and again, there will be cases where a country will allow all forces to do so, and other cases where only support forces such as tankers and airlifters will be allowed to transit. Such access to enroute bases is necessary to any major deployment of land-based forces, both because Air Mobility Command airlifters must stage through them, and because air-refueling tankers must operate from them in order to refuel deploying aircraft. The same constraint applies to global bomber operations launched from the continental U.S., which are utterly dependent on access to enroute bases on foreign territory for use by KC-135s and KC-10s.

In addition to gradations in the scope of access granted U.S. forces, are gradations in the timing with which that access is granted. As noted in the first section, it took the Saudis four days after the Iraqis invaded Kuwait to decide that a massive deployment of American forces would be in their security interest. The speed of the deployment that followed was inestimably aided by the massive pre-positioning of U.S. equipment that the Saudis had agreed to during the Cold War. Thus, a country that already had a major military relationship with the United States, and which had allowed extensive pre-positioned stocks of equipment to be deployed on its territory in anticipation of a scenario like the one it faced in August 1990, still took days to decide how to respond. A country with a more tenuous relationship with the United States to start, and one that would be lacking in the pre-positioned stocks that make large, rapid deployments of land-based forces possible, might understandably pause even longer over whether to grant U.S. forces access to its bases.

Operation Enduring Freedom has provided myriad examples of these various gradations of access in both time and scope for land-based forces. The central points about this experience are two: the access eventually gained has over time become extensive, but the process that produced this access began after the need for the access emerged, was protracted, and the results were utterly unpredictable from the vantage point of September 10, 2001.

Military Constraints on Access to Bases Ashore

The technical trends affecting the military security of overseas bases provide a case where the demands of the near and far term security environments appear to reinforce each other, even though the source of this similarity is different. This is because fixed bases within a radius of 500 to 1000 miles of an opponent are likely to become increasingly vulnerable in the near to mid term to conventional attack by GPS/INS-guided ballistic and cruise missiles. Over the longer term, this vulnerability to over the horizon attack will extend to large ships at sea, but in the near to mid term, such ships are likely to be more survivable than fixed land bases as long as they stand off over the horizon from an opponent. Least likely to become vulnerable out through the far term, some 30 or more years from now, are undersea and space platforms, although the latter, particularly when deployed in low earth orbits, will likely eventually become more vulnerable than the former. Fast, quiet nuclear submarines will remain the least vulnerable of all basing modes because antisubmarine warfare (ASW) is least affected by the technical trends that will potentially transform other warfare areas. Thus, ASW against modern nuclear submarines will remain both extremely demanding technically, very expensive, and still a largely fruitless endeavor.

The trends in the vulnerability of fixed bases within a theater will be driven in particular by the marriage of cheap, widely available GPS/INS guidance technology and conventional sub-munition payloads with existing, mobile, tactical ballistic missiles (TBMs) and cruise missiles. Cruise missiles will likely be chosen if an opponent wishes to extend his reach beyond about 600 km.¹ Such cruise missiles might actually have more in common with small aircraft than with current cruise missiles like Tomahawk, and might derive their survivability less from high speed and low radar cross section than from their ability to blend in with a noisy background and deny an opponent positive identification.² This discussion will focus on TBMs because they are already ubiquitous.

Before discussing the impact of GPS/INS, it is important to establish what is already true about existing mobile TBM capabilities. TBM defenses have already proven to be at the edge of the scientific-technical capabilities of the United States, and even assuming effective TBM defenses in the future, they will likely be on the losing end of the cost-exchange ratio between the attacker and the defender. Directed energy weapons may change this relationship in the distant future, but even directed energy weapons will be most effective against anti-ship missiles whose warheads must have terminal seekers, because it is more difficult to harden the latter against a laser's heating than it is to harden an INS/GPS-guided warhead used in attacks against fixed targets.³ Heretofore, the TBM threat has been

leavened by the fact that they have been very inaccurate. Armed with conventional warheads, their military effects have been both low and unpredictable, and armed with nuclear, chemical, or biological warheads, their use would bring the vastly superior American deterrent into play.

GPS/INS will lead to a quantum leap in conventional TBM capabilities because it will give them the accuracy needed to attack soft, fixed military targets with conventional submunition payloads. This is a capability that has already been deployed by the U.S. in the form of the U.S. Army's Tactical Missile System (ATACMS). Single stage TBMs like the Chinese M series already provide ranges of 300-600 km (185-375 miles), payloads of 500 kg (1100 lbs), and conservatively estimated accuracies of 100-200 meters (330-660 feet). A 500 kg payload of simple submunitions like the M-77 grenade can destroy soft targets over a circular area of two million square feet centered at their point of release. Even with the relatively low accuracies assumed above, TBMs like this would wreak havoc on airfields and ports within their range. For the purpose of this discussion, I will focus on airfield vulnerabilities, and in particular on those vulnerabilities most relevant to the mid to far term security environment.

Airfields within range of opposing TBMs will be inherently vulnerable in the expeditionary environments typical of likely future air operations for four reasons. First, simply building the hardened shelters to protect five 72 aircraft wings of tactical fighters is a major, multi-billion dollar investment that few potential allies are likely to make on their own. Second, in a world where the location of future conflicts is less predictable than it was during the Cold War, the U.S. will not be able to invest in hardening airfields in all the potential areas where it may be called on to fight. Third, even in cases where the United States did make this investment during the Cold War, as in Saudi Arabia, it still proved too expensive to provide shelter to the thousands of U.S. personnel which must live and work on the base; hence the enormous tent cities which were erected on base, which would remain a lucrative target even at the hardest base. Finally, it is simply impossible to provide hardened shelters for the various large, high value support aircraft which are integral to any expeditionary air operation, such as AWACS, JSTARS, Rivet Joint, KC-135 and KC-10 tankers, and outsize airlifters like the C-5 and the C-17.⁴ For all these reasons, it is likely at some point in the mid to long term future that large scale, expeditionary deployments of tactical combat aircraft and supporting assets will become limited by the need to avoid bases within 1000 miles of an opponent's territory.

This constraint will, at a minimum, reduce by half or more the sortie rate of a given size force of tactical aircraft, and increase the cost in terms of additional tanker support and bases for those tankers necessary to give that force the range to attack a given set of targets. Perhaps more important, there will be circumstances due to the political geography of a particular conflict in which the only bases potentially available will be within range of an opponent's missile force. This will lead to cases where land-based tactical aircraft will be denied access to a given theater altogether, or at least until the threat to their bases has been suppressed or eliminated by other forces.

The Special Case of Bombers and Overseas Bases

Land-based bombers use their much greater range than land-based tacair to reduce the number and/or the political salience of the overseas bases they use, and to increase the standoff range of those bases from the opponent. Politically, bombers can reduce their vulnerability to denied access simply by increasing the probability that an amenable ally can be found within range of the opponent. They can also reduce their vulnerability to being denied access by taking advantage of the fact that a country is more likely to allow tankers rather than combat aircraft to operate from its bases. Taken to its extreme, this latter tactic can involve 30-40 hour round trip missions for the bomber and its crew between the United States and a target half way around the world. In these operations, the bomber never uses a foreign base, but the vast array of tankers that must be pre-deployed along its route must do so intensively. Thus, it is almost never the case that long range bombers eliminate all dependence on access to foreign bases. What they do in almost all cases is lessen that dependence below the political threshold that can lead to access denial.

Added range is not a free good, which is why bombers are much larger and much more expensive than tactical fighters, and tend to be slower. Also, though their size gives them larger payloads, the added range over which they carry those payloads leads to reduced sortie rates. Finally, in contested air space, bombers cannot defend themselves against opposing air defenses, which precludes independent operations by B-52s and B-1s, and precludes daylight operations by B-2s. These tradeoffs between bombers and land-based tacair will become more important when military vulnerabilities at overseas bases are added to the political vulnerabilities that already exist. Assuming that there will be limits on the range of these threats for the foreseeable future, they will improve the relative advantages of long range aircraft compared to expeditionary tacair, because bases outside that range will not need to be defended and/or hardened.

Air bases and other relatively soft, fixed targets will become more vulnerable because mobile, long range, GPS/INS guided weapons that are difficult to defend against will be increasingly available to potential opponents. But as the U.S. discovered in the skies over Kosovo, such weapons do not by themselves address the mobile target problem. Thus, potential opponents of the U.S. will likely succeed first at solving the fixed target problem before they become adept at the mobile target problem. As will be discussed below, the key to the mobile target problem is a wide area, over the horizon search and surveillance capability. Different warfare areas will present different challenges to future opponents that wish to develop such surveillance capabilities. One such warfare area is sea denial, a posture normally forced on the weaker contestant in a naval battle that seeks to prevent its more powerful opponent from projecting power across or from the sea.

Military Constraints on Access From the Sea

As a subset of the warfare areas where the mobile target problem dominates, sea denial presents an interesting set of extremes. In a purely technical sense, over the horizon surveillance of surface shipping is probably the easiest form of mobile

target surveillance, while surveillance of submarines is by far the most difficult. Surveillance of surface shipping is relatively easy because surface ships present an easily detectable signature to airborne radars. The main reason is that the sea surface is a relatively clutter-free environment. For example, the sea presents itself as a flat, mirror-like surface to UHF radars of the type used on today's E-2. Therefore, ships on the horizon stand out against this background without need for resort to the doppler signal processing necessary for airborne radars to detect moving targets on land. Of course, such surveillance of surface shipping is still bedeviled by the clutter caused by commercial shipping, and by the need therefore to classify targets as friendly, neutral, or hostile.

By contrast, the only effective long range surveillance technique against submarines has been and largely remains passive acoustics. Passive acoustic surveillance systems are quite effective against loud targets, and surprisingly simple, as demonstrated by the development and wide deployment by the U.S. of the Sound Surveillance System (SOSUS) quite early in the Cold War. Yet the key constraint on such systems is that, like all passive detection methods, they rely on a cooperative target. That is, systems like SOSUS are only effective against submarines that put a narrow band signal into the water. Eliminate those narrow band tonals, as the U.S. submarine force began to do aggressively in the early 1960s when it discovered its own vulnerability to SOSUS, and passive acoustic detection ranges plummet against quiet submarines.

Recovering the detection ranges provided by passive acoustics against a non-cooperative submarine is extremely difficult. The Soviet Navy faced this problem throughout the Cold War and never came close to solving it. The U.S. Navy only began to face it near the end, with the Soviet deployment of submarines like the Akula SSN. On a much different scale, and in a much more confined set of circumstances, this problem continues for the U.S. in the form of modern, non-nuclear submarines.⁵ There is no one solution to the surveillance problem against these submarines, but an example of what will be required is provided by current U.S. Navy efforts to incorporate legacy passive acoustic sensors deployed on individual platforms into a multistatic processing network for detecting faint echoes from a small target using an artificial sound source in an extremely high clutter environment.

Similar asymmetries exist in the weapons available to an opponent for ASUW and ASW. In the former warfare area, radar-guided, fire and forget weapons have been in operational use for more than 30 years, and rely again on the large, clutter free signature provided by the outline of a ship against a clearly defined horizon. Flying low and fast, antiship missiles are extremely difficult to defend against in the end game of their engagements, which is why the U.S. Navy's traditional approach to countering such missiles has been to mount a major effort to attack their launch platforms. Despite the relative success during the Cold War of these efforts to kill the archer rather than his arrow, the Navy was still driven to develop the most sophisticated radar guided SAM system in the world, in the form of the Aegis defense system, which is devoted to killing the arrows that leak through a battle group's carrier-based outer air defenses or, in the more challenging case of a submarine launched antiship weapon, its ASW screen.

Today, the danger posed by antiship weapons is manifest in the proportion of a U.S. Navy guided missile destroyer's or cruiser's VLS tubes dedicated to carrying SAMs rather than offensive weapons like Tomahawk. On an Aegis equipped ship, this proportion is around 60-70 percent. The danger is also manifest in the development of sophisticated systems like the Cooperative Engagement Capability (CEC), which will form a network of the monostatic radars in a battle group. This network will allow those ships optimally located to detect an antiship missile from the side, where its radar signature is the largest, to guide the weapons of another ship, optimally located to attack the antiship missile, but unable to see it because of its low frontal aspect cross section.

ASW weapons, predominantly torpedoes, come in two types: wire-guided torpedoes that are controlled by their launch platform until the end game, when they go active; and "fire and forget" torpedoes which use active sonar from the start. Wire-guided torpedoes are long range weapons primarily for use in cases where the weapon platform can approach and attack its prey passively and ambush it, which is why they have only been carried by attack submarines. In cases where the attacking submarine has a good enough acoustic advantage over its opponent, wire-guided torpedoes are by far the most effective ASW weapon. Because U.S. nuclear submarines are so quiet, and because they are normally immune to long range surveillance, they will encounter the submarines of a potential opponent in only two cases: when they are about to kill them, or in an accidental encounter; which is why few countries will even bother to use their submarines in an ASW mode, except of course in self defense, when a wire-guided torpedo is relatively useless.

Wire-guided torpedoes are also incompatible with air ASW platforms. Thus, during the Cold War, shorter range, active, lightweight torpedoes were the weapon of choice for maritime patrol aircraft and ASW helicopters. Lightweight torpedoes were used effectively during the Cold War by the U.S. Navy because they were deployed on air ASW platforms that could use passive acoustics to get very close to the target before launch, usually within the low thousands of yards necessary to detect the anomaly in the earth's magnetic field caused by its steel hull. Also, because Cold War air ASW was a largely a deep water exercise, these active torpedoes operated in a relatively clutter free environment, and because it occurred in blue water, their launch platforms were operating in benign air space.

Understanding the conditions enabling air ASW and the use of lightweight torpedoes during the Cold War is important because this is the only ASW posture that will be available to potential opponents of the U.S. for the foreseeable future. Yet none of the enabling conditions described above will apply. Opposing ASW forces will not be able to use passive acoustics to locate and track American submarines at long range. Instead, the only potentially useful detections will occur intermittently, when those submarines launch salvos of surface-to-surface weapons, and those detections will only be useful if they are made by radars deployed within line of sight of the those weapons soon after they break water, before trajectory shaping masks the point of break water beyond utility. Furthermore, even should these conditions be met, this initial datum will rapidly lose its utility as the submarine quickly leaves the launch area at maximum quiet speed. In order to take advantage of such a datum, the opponent would need to be

able to close it with an air ASW platform quickly enough to allow the latter to search for and acquire the American submarine using active sonobuoys or a helicopter's active dipping sonar, both of which would be limited by reverberation to detection ranges of a few thousand yards. Finally, assuming successful accomplishment of the preceding chain of events, the opponent's air ASW platform would need to be armed with lightweight, 45 knot torpedoes whose active seekers could filter out the very high clutter and reverberation characteristic of a shallow as opposed to a deep water environment, and still home on and run down a target which, upon detecting that it was being successfully tracked by the weapon, could quickly accelerate to a speed of 30 plus knots.

Comparing Military Constraints On Access to Bases Ashore and On Access From the Sea

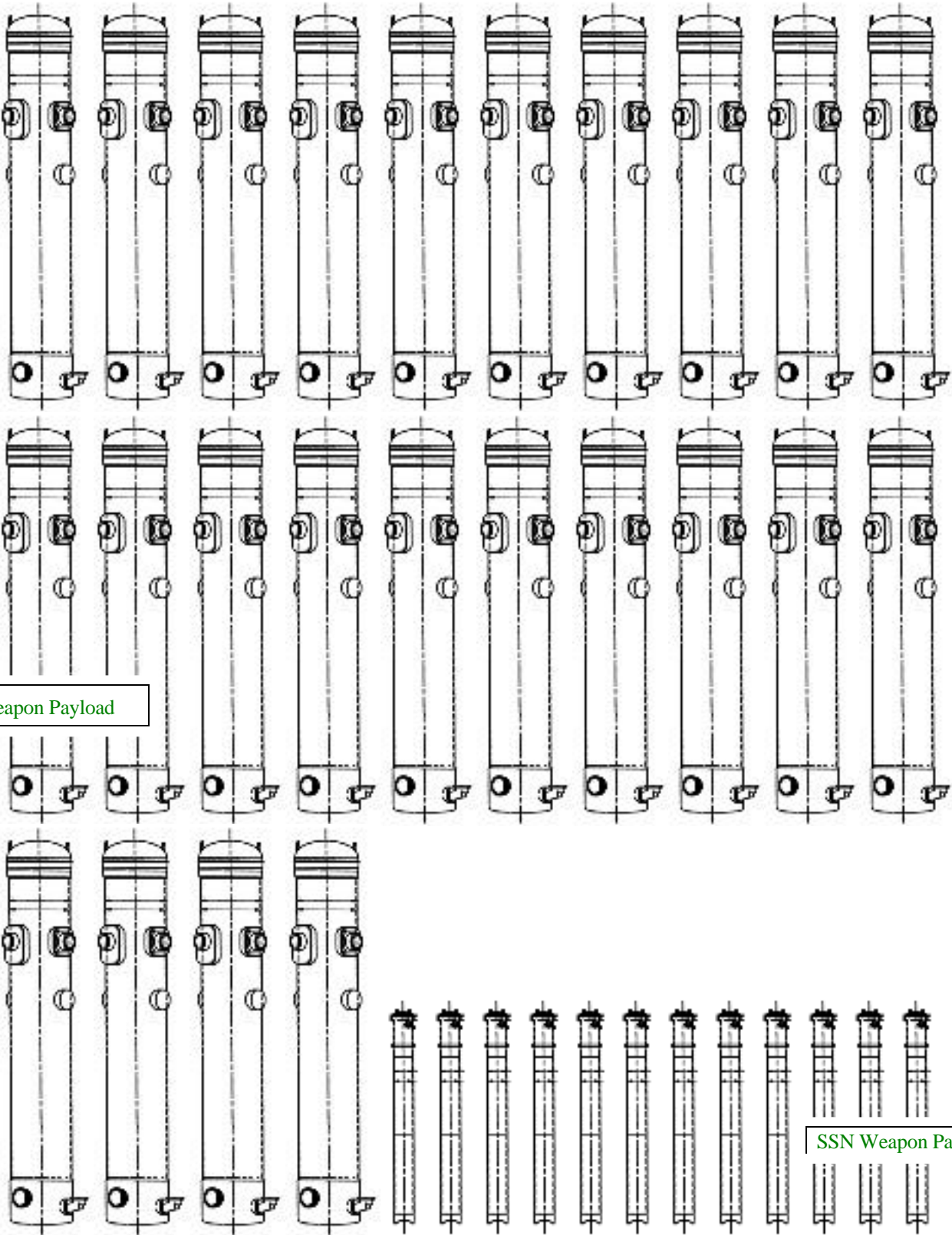
Given the difficulties inherent to the ASW problem, it is relatively easy to show that potential opponents will have more difficulty solving that problem than they will the antisurface sea denial problem. More important for our purposes is the question of how much more difficult the antisurface warfare (ASUW) problem will be compared to the problem of attacking soft, fixed targets like air bases. The most straightforward and technically manageable approach to an over the horizon, ASUW denial capability would resemble aspects of the old Soviet approach to this problem, especially its emphasis on long range patrol aircraft using surface search radars and ELINT to locate and classify hostile combatants. These assets could be used to cue attacks by surface ships, aircraft, and submarines. Of course the problem with this approach is that the patrol aircraft are not survivable in wartime.

It is important to note that this approach still allows a potential opponent to trail U.S. forces in peacetime and strive for a victory in "the battle of the first salvo" that would occur when conflict broke out. Certainly, this approach caused much concern when it was applied by the Soviets to the Sixth Fleet in the Mediterranean naval operations conducted during the Fall 1970 Jordanian Crisis, and later during the October 1973 Yom Kippur War. But there are tactics that can greatly limit the effectiveness of such an approach, and dissatisfaction with this limited capability led the Soviets to pursue a space-based solution to their over-the-horizon, ASUW surveillance problem.⁶ The constellation of radar and electronic ocean reconnaissance satellites (RORSAT and EORSAT) that they first deployed in the 1970s was the result.

It is not clear how successful this system was, but there is some considerable evidence that the U.S. Navy developed tactical and technical countermeasures to it which reduced its effectiveness in detecting, identifying, and tracking the Carrier Battle Groups which were its prime target. Prime among this evidence is the fact that the Soviets never reduced their fleet of maritime patrol aircraft, and in fact modernized it long after deploying RORSAT and EORSAT. This demonstrates two things: that the mere fact of an ability to deploy surveillance or reconnaissance satellites does not confer a surveillance or a reconnaissance capability; and that therefore one way of measuring the difference between addressing the fixed target problem and the ASUW sea denial problem is to measure the difficulty of developing an effective space-based ocean surveillance system. Clearly, the latter is far more challenging for a potential opponent than simply obtaining the GPS coordinates of regional air bases in advance of a conflict, and it is also more challenging than developing a space-based imaging capability for use in monitoring the use of those regional bases on a daily basis.

On this basis, one can certainly argue that an ASUW denial capability will be more difficult for an opponent to develop than an ability to attack soft, fixed targets. This means that naval surface combatants and aircraft carriers will be more successful for longer in defending themselves against opposing sea denial efforts than will land-based, expeditionary tactical air forces that seek to

operate from soft bases within range of opposing TBMs and cruise missiles. But it also means that these surface naval forces will carry a much larger self defense burden than will fast, quiet nuclear submarines, which will be able to devote all of their payloads to offensive weapons because they will be essentially immune to opposing ASW sea denial efforts for the foreseeable future.



One key to destroying access denial forces will be sources of forward deployed weapon payload that are both invulnerable and persistent. A Trident SSGN will

combine the invulnerability and persistence of an SSN with the missile payload of a Carrier Battle Group.

Destroying Rather Than Merely Suppressing Access Denial Forces

One of the main differences between political and military constraints on access is that political constraints tend to result from structural aspects of the security environment. For example, the shift from formal alliances to more informal coalitions is at least in part a consequence of the end of the Cold War and the unifying threat which that struggle posed to the members of NATO and to Japan. As a structural change, this shift is irreversible in the near to mid term, and its consequences are therefore not manipulable.

By contrast, military threats to access, though influenced by underlying technical trends, are manipulable. It is possible to counter many military threats in a way that either defeats or avoids them, especially for a country like the United States, which can commit sufficient resources to defense to win some asymmetric military competitions simply by using brute force. That said, even for a country as wealthy as the United States, it is important to avoid brute force solutions where possible because they are so inefficient. The principle of the Economy of Force can be violated when necessary, but as a rule, too great a reliance on brute force will eventually be the downfall of even Goliath. One goal for DOD's transformation should therefore be the replacement of brute force methods of suppressing opposing access denial forces with methods that replace mass with precision and suppression with destruction. This section will show that the rapid and precise destruction of modern ground-based air defenses is the area where such a transformation effort will likely be most rewarding.

Diesel submarines, mobile, precision-guided, conventional tactical ballistic missiles (TBMs), and mobile, radar-guided surface-to-air missiles (SAMS) have several things in common. They will probably be the weapons of choice for those who wish to fight superior U.S. power projection forces in the future. They are very hard to find unless they seek engagements, and they are very hard to destroy unless they press home those engagements. Therefore, because they can threaten battle without being destroyed, and because they pin down superior forces, they can be used by an opponent as a threat-in-being. The strategy of maintaining a threat-in-being descends from the naval concept of a fleet-in-being:

"Yet a fleet which elects to refuse battle does not by that fact cease to be a threat. It is likely at any time to leave its base for destructive sorties. That kind of strategy on the part of the inferior fleet - of avoiding battle but retaining the maximum possible threat value (is) known as the strategy of the 'fleet in being.' Such a fleet requires watching; its menace can be countered only by keeping a superior force constantly ready to intercept and engage it should it advance too far from its base."

Preventing an opponent from using its access denial forces in this fashion will require two capabilities. First, the United States must be able to project sufficient power while these access denial forces are still extant to force them to seek engagements. Second, the United States must structure its forces so that they can quickly destroy rather than merely suppress or evade access denial forces when they do seek engagements.

The similarities between these access denial forces break down when one begins to look at the details of how U.S. forces might accomplish this goal. The threat posed by diesel subs and TBMs can be countered by standing off, albeit with an accompanying penalty measured in significantly lower sortie rates for strike aircraft. Likewise, a force of SAM-10s held in reserve could hold at risk any air breathing platform within line-of-sight of the opponent's coast. But in this case, standing off from the threat will lead to a qualitative rather than a merely quantitative reduction in the power projection capability of U.S. forces because it will prevent them from deploying the sensor networks it needs to find and attack mobile targets ashore.

For example, diesel submarines will become much more vulnerable if they seek to attack carrier battle groups operating several hundred miles out to sea. By exploiting sea room and speed, the Battle Group can force a diesel sub to make a long, high speed approach if it wishes to attack, which will significantly increase its acoustic signature, while at the same time draining its battery at exactly the point when it needs to preserve its battery if it hopes to survive the engagement. This is why diesel subs thrive in environments when their prey must come to them in their home waters, or at nearby focal points. By avoiding such areas of operation, Battle Groups can evade the threat, but at the expense of reduced sortie rates and persistence by their air wings because the latter must operate at a greater distance from the opponent's air space. Here is a case of virtual access denial where the opposing submarine and the Battle Group never meet, and it illustrates both the difficulty and the value of developing a capability to quickly find and destroy diesel subs even when they are being withheld in home waters.

The story is similar regarding TBMs attacking nearby air bases and ports. Mobile TBMs in the field are as hard to find and attack as are diesel subs. Once launched, they are arguably more difficult to defend against. And when used against fixed targets, they are easier to target because their prey does not move. On the other hand, most mobile TBMs using conventional payloads are only effective against relatively soft targets, and they are limited in range by the need to remain road mobile - approximately 600 kilometers. Road mobile cruise missiles can extend this range out to roughly 1000 miles with some loss in payload carried. Expeditionary air wings seeking to operate from unsheltered bases within range of such a threat would be in great danger even if the bases were provided the best ballistic and cruise missile defenses. Absent hardened bases, they will have no choice but to "stand off" from the threat, but both politics and geography will complicate the search for safe operating bases. This is why, in contrast to sea-based forces, it has become so difficult to predict with any certainty the role that shorter-ranged, land-based air power will play early in future conflicts.

Longer range, land-based bombers will have more predictable access than their shorter-legged cousins because they can efficiently operate from outside the range of opposing TBMs and cruise missiles. But compared to carrier-based fighters, they will pay an even steeper price in reduced sortie rates because reliable bases like Diego Garcia and Guam are at least 2000 miles from the Indo-Pacific littoral. On the other hand, even when operating at long range, bombers will have greater endurance over the battlefield than fighters, and will carry much larger payloads.

Thus, among traditional sources of projecting air power, land-based bombers and carrier battle groups can to some extent evade the military threats posed by diesel subs and land attack missiles by standing off, albeit at significant cost to their sortie rates and persistence over the battlefield.

The problem with this team is that it currently lacks a good solution to the third leg of the access denial triad - mobile, radar guided SAMs, and particularly "double digit" SAMs like the SAM-10. The current approach to dealing with mobile SAMs leads only to their suppression rather than their destruction, and Serbia exploited this to pursue a successful threat-in-being strategy with its SAM-6s during Operation Allied Force. This experience has led to an interest in systems that can destroy SAM batteries, and particularly their engagement radars, even if they do not press home their engagements, i.e. destruction of enemy air defenses (DEAD) rather than mere suppression.

Current mobile SAM systems can survive in the face of our defense suppression capabilities by following two operational guidelines. First, when actually engaging a strike package, they know to shut down their engagement radars when they recognize an incoming HARM antiradiation missile, which is not difficult because HARMs are the only MACH 2+ weapon they are ever likely to see. As long as they do this, the HARM will lose its guidance and miss the radar. Second, once they have participated in an engagement, they know that if they move as little as 500-1000 meters within 120 minutes of shutting down their radars they can usually prevent the U.S. from targeting them with follow on strikes, unless aircraft from the recently engaged strike package are able to locate and attack them visually. That is because it currently takes at least two hours for the U.S. to convert an ELINT cue off an active SAM radar into a mensurated SAR image and a strike by a GPS-guided weapon like JDAM or Tomahawk.

This mode of operation rarely leads to successful engagements against U.S. strike packages, but it also ensures the survival of an enemy's mobile SAM systems, which they can use as a threat in being, forcing the U.S. to form all penetrating aircraft into strike packages and escort them with scarce defense suppression assets throughout a conflict. Because defense suppression assets are scarce, an enemy can thereby put an upper bound on our strike capabilities that is much less than our potential, much as a shortage of destroyers can greatly reduce the carrying capacity of a large merchant fleet when convoying becomes necessary. And because they only suppress enemy defenses for the length of time that antiradiation missiles are in the air, our defense suppression assets only enable fleeting access to contested air space.

In the future, this will deny UAVs and manned strike aircraft a persistent presence over the battlefield, thereby denying us the persistent surveillance and

time critical weapon delivery necessary for successfully attacking mobile targets. This is perhaps the most important problem associated with our current defense suppression posture: it allows an enemy to protect its mobile forces in the field from concentrated air attack as long as they do not maneuver en masse or remain static in large, fixed positions. Thus, the transition from a defense suppression to a defense destruction capability is both necessary to enable effective attacks against mobile targets, and is itself an example of one aspect of the mobile target problem, in that the most modern SAM systems are themselves mobile targets. Thus, a focus on making the transition from suppressive to destructive fires against enemy air defenses is doubly important.

The DEAD options being considered by the Air Force and by Naval Aviation all depend on relatively short-legged strike fighters. They will be effective in destroying older SAMs like the SAM-6 when they engage penetrating strike packages that are provided the appropriate escorts. But they will be less capable of preventing double digit SAMs from holding air breathing surveillance platforms at risk for several reasons.

First, systems like the SAM-10 have engagement ranges of at least 100 miles, which means that weapons used to attack them must be long range, standoff weapons. But it is difficult to provide precise GPS targeting information for such weapons in real time, and unless the weapons are made stealthy, their time-of-flight is such that they provide ample warning to the SAM battery that it is under attack, giving the battery a chance to break down and move, and the weapons themselves will be vulnerable to interception if the SAM battery chooses instead to stand and fight.

Second, in an access-constrained environment, strike aircraft will be relatively scarce, and tactical aircraft particularly so. The overall scarcity of strike assets means that it will be difficult to generate "first day of the war" threats to the opponent's vital interests, which in turn will make it difficult to force him to expose his access denial forces. This challenge becomes even more difficult if all or most of the available tactical fighters must be used not only to provide escorts for penetrating strike packages, but also as escorts for permanent orbits of multiple, long endurance surveillance platforms. As long as the opponent's air defenses can pursue this threat in being strategy, they will drain tactical aircraft away from strike missions, and they will also be able to force high value surveillance platforms to stand well off from the battlefield.

These constraints create a vicious circle that will worsen in direct proportion to the scale of the overall access constraints that U.S. forces encounter. The greater these constraints, the more U.S. forces will have to stand off and the less striking power they will be able to bring to bear, and the more sensors have to stand off, the less ability there will be to find and attack mobile targets, including those which themselves force U.S. forces to stand off.

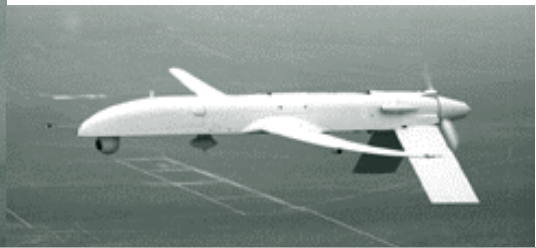
In many ways, the key to breaking this circle will be the destruction of mobile, long range SAMs. Their destruction will reduce the inefficiencies associated with escorting aircraft in contested air space, and will increase the ability to push airborne sensor networks forward, whether to go after mobile TBMs ashore, or to

help in the close in fight against diesel subs, swarms of missile-firing boats, and mines.

Fortunately, there is a key difference between mobile SAMs on the one hand, and diesel subs and land attack missiles on the other. The latter do not need to emit powerful signals, vulnerable to long range detection, in order to target their weapons. Therefore, if the U.S. cannot infest their operating areas with active sensors, they are extremely difficult to find. By contrast, radar-guided SAMs are dependent upon their radars to function, and this introduces a point of leverage for U.S. forces.

To exploit this point of leverage, U.S. forces must concentrate large amounts of striking power on platforms which can operate with persistence close to the opponent while remaining largely immune to its access denial forces. The weapons on these platforms will pay little or no "standoff penalty" and will therefore also be a constant source of time critical fires. At the same time, U.S. forces must deploy networks of persistent sensors for use in targeting time critical fires, especially against double digit SAMs. This will give U.S. forces the ability to engage in decisive power projection against both fixed and mobile targets from the first day of a conflict even when the access constraints facing traditional forces are high.

The discussion that follows will look in more detail at the general problem of finding, targeting, and attacking mobile targets. Most current discussions understate the technical and operational obstacles blocking solutions to this problem. These obstacles fall broadly into two categories: developing sensor networks that can identify and precisely locate mobile targets; and developing time critical fire networks that can quickly attack those targets when they are found. The discussion will focus when necessary on the specific requirements of destroying mobile SAMs because that mission is the precursor to so many other access enabling missions.



Persistent surveillance over the battlefield by air breathing platforms will be key to detecting, identifying, locating, and tracking mobile targets for the foreseeable future. Ensuring their access to future battlefields will require an ability to destroy rather than merely suppress or elude double digit SAMs

Locating Mobile Targets and Quickly Attacking Them

The main military lesson of Enduring Freedom is the value of networks that provide persistent surveillance, time critical targeting, and a ready supply of precision weapons deployed within minutes of their targets. Over Afghanistan, these networks were formed in ad hoc fashion using existing assets, and their use was possible because Afghan air space was uncontested. No asset used in the skies over Afghanistan was unavailable to U.S. military commanders during Allied Force. The difference was that Serbian and Kosovar air space remained contested throughout Allied Force. In the future, such networks must be designed to function in contested air space, better methods of winning total control over contested air space must be developed, or some combination of both these approaches must be adopted. In practice, better approaches to rapidly destroying rather than merely suppressing or evading advanced air defenses will pay a huge premium, because it is very difficult to build a network for finding and attacking mobile targets in contested air space.

Persistent surveillance is important because most mobile targets become detectable only intermittently, when they move, radiate, or fire a weapon. In order to detect these intermittent events, a sensor must be staring at the area of concern, rather than passing periodically overhead. But the full value of a network of sensors staring at the battlefield can only be exploited if these mobile targets, once found and tracked, can be quickly attacked. Otherwise, even the most sophisticated sensor network will either lose its track of a particular target, or over time, be overwhelmed with the need to maintain an increasing number of tracks.

Therefore, alongside the demonstrated need for staring surveillance networks, is the need for a time critical strike network in which weapons are delivered to aimpoints designated by the surveillance network within minutes of the initial request. Such a network was improvised during Enduring Freedom by using "cab ranks" of naval fighters and long range bombers orbiting over areas of interest while they were being surveilled. Surveillance was accomplished by large, non-stealthy UAVs loitering over the battlefield at low-to-medium altitudes day and night without escort, and by SOCOM forces on the ground that were able to operate with relative freedom because of the frequent absence of well defined enemy lines.

Providing Persistent Surveillance and Targeting

Sensor networks vary according to the medium in which they are deployed, the phenomenology that is being exploited, the aperture of the sensors being used, whether individual sensors operate autonomously or whether their output is fused, whether the sensor platforms are manned or unmanned, whether their output is processed or unprocessed, the bandwidth of its data links, and their survivability and persistence over the battlefield.

For example, a radar associated with a SAM-10 battery is a mobile target, but it must remain stationary and emit powerful RF signals to do its job. Given a cue that it is about to come under attack, it can break down and move to another location. The best way to detect and identify a mobile radar while it is operating is to intercept its emissions using space or airborne electronic intelligence

(ELINT), but if this interception is accomplished using today's non-networked systems, the location error of the radar is too large for use in targeting GPS-guided, standoff weapons because single platform, passive ELINT sensors do not calculate the range to the target well.

In order to estimate range, they must measure the angle of arrival of a radar's signals several times along as long a baseline as possible because the best accuracy in range estimation results when the baseline is long relative to the distance to the target. But in practice, this implies either that the ELINT platform must fly close to the target to quickly generate angle rate against a brief signal, or that the target signal must be continuous for at least several minutes so that a standoff platform has the time to generate a long baseline.

The first approach is currently used by Wild Weasel aircraft to target pop up radars, while the second approach is used by ELINT aircraft like the RC-135 and the EP-3 to target radars from a distance. Today, both of these approaches are used to provide targeting information to HARM missiles that can tolerate large target location errors, assuming of course that the threat radar cooperates by continuing to emit in the face of attack. This means that a capability to attack non-cooperative radars will usually require another sensor to provide precision location.

Synthetic aperture radars (SARs) on airborne platforms can do this as long as the SAR is within range of the threat radar (50-150 miles depending on the size of the SAR's aperture, or antenna), has a clear line-of-sight to it, and the threat radar does not move. A SAR creates an image of the target and compares that image to a stored, digital model of the terrain in the area that is registered within the global grid of latitude and longitude. By matching the terrain surrounding the target with the terrain in the data base, the location of the target can be estimated with good precision. This process is called mensuration. Today, mensurated SAR images can be produced on the ground after high altitude radar platforms like U-2 or Global Hawk have downlinked raw, very wide bandwidth SAR data to ground stations where the data is processed, or by widebody radar platforms like JSTARS and the experimental P-3 "Hairy Buffalo," which can mensurate SAR images on board, but which suffer from a lower viewing angle of the battlefield.

Either approach today can require more than an hour to get targeting information from the SAR to a weapon platform. But a SAR's targeting solution will remain useful only so long as the threat radar remains stationary. If the radar moves before being struck by a weapon, it will escape and the targeting process must start from scratch unless still a third sensing method is brought to bear, a radar that can indicate targets moving on the ground (GMTI). In practice, most ground surveillance radars can use either the SAR or GMTI mode, but not at the same time.

A radar using the GMTI mode gains the ability to detect moving targets at the expense of being able to locate them precisely. This is because, unlike ELINT systems, an MTI radar has excellent range resolution but relatively poor resolution in azimuth. (In the SAR mode, a radar obtains good resolution in azimuth through signal processing tricks which give it an artificially large aperture. These tricks require a stationary target). Thus, GMTI radars can best be used to maintain a track on a vehicle until it comes to rest again, at which point a SAR

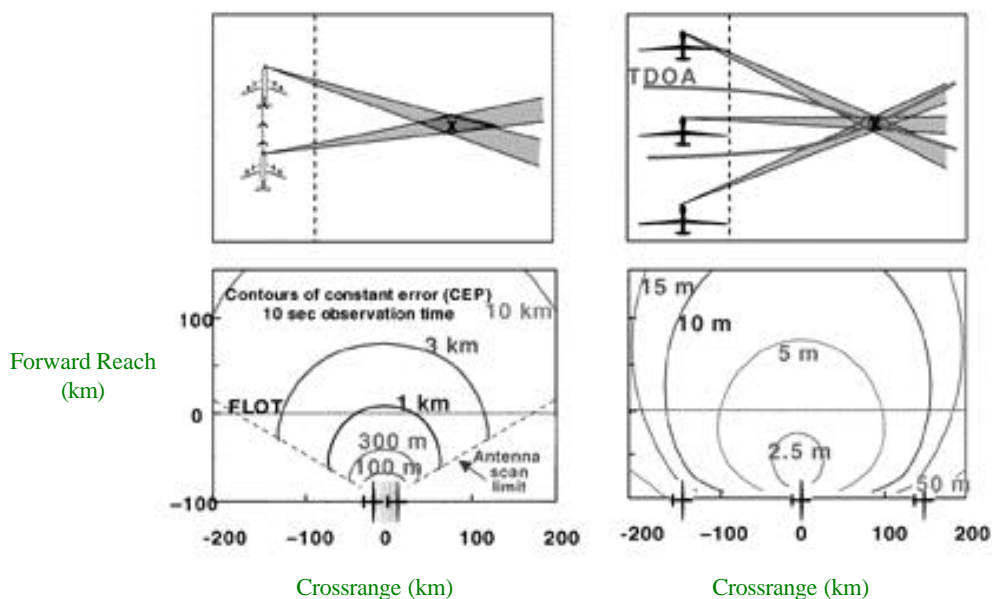
can image and geolocate it. But today's MTI radars have trouble maintaining tracks on individual vehicles when they merge with other traffic, and they also have a limited capacity to maintain multiple tracks at the same time, which means that once moving, it will be difficult to ensure a track on the threat radar, which in turn puts a real premium on successfully attacking it after it has revealed itself by emitting, but before it breaks down and moves.

Two developments will likely address some of the constraints described above within five years. One would greatly improve the target location accuracies provided by ELINT systems, and the other would improve both the target location and the target identification capabilities of SAR/MTI radars. Both sets of improvements depend

ing

Today: Single platform AOA
Single RC-135

Future: Multi-platform TDOA
Three Global Hawks



In the case of ELINT, if three ELINT antennas are deployed within line-of-sight of an emitter and data-linked together, they can be used to measure both the frequency and time of arrival of a single radar pulse at three widely separate locations. If the outputs of the three sensors are compared over a very short period of time, the emitter can be identified, and its location precisely determined using time difference and frequency difference of arrival (TDOA and FDOA) signal processing. ELINT networks using TDOA/FDOA signal processing depend on very good data links between the three platforms, and their performance varies in roughly descending order according to the geometry of the three sensors relative to the emitter, the distance of the sensors from the emitter, and the aperture of the ELINT antennas used. The ideal geometry has the three sensors essentially surrounding the emitter, separated from each other by roughly 120 degrees.

One of the great strengths of TDOA networks is that they do not require sophisticated, large aperture antennas. This means that there is great flexibility in designing the nodes in a TDOA network. For example, where groups of aircraft are already present on the battlefield for other reasons, it may be possible to

turn them into a TDOA network by linking their Radar Warning Receiver (RWR) or Electronic Support Measure (ESM) antennas via Link 16. Alternatively, because the antennas can be so small, TDOA nodes could be deployed on UAVs much smaller than those required to deploy radars. Thus, because the nodes are passive, and because they can be deployed on very small platforms, a TDOA ELINT network might be the only kind of targeting network that could be deployed in the face of advanced air defenses.

In the case of SAR/MTI radars, if three widely separated radars are deployed within line-of-sight of a moving target and data-linked together, the error in target location caused by errors in azimuth resolution can be greatly reduced by fusing the error ellipses of each radar and finding their intersection. This may allow moving targets to be tracked by MTI radars with an accuracy approaching that provided by a SAR used against a fixed or stationary target. At the same time, work is being done to give individual SAR/MTI radars a better capability to identify moving targets. One technique exploits the excellent range resolution of these radars to form a crude image of the moving target, a technique that is also being developed for advanced air-to-air radars. A second technique inverts the SAR radar's normal routine by using the target's motion to exploit the doppler effect of an object rotating relative to the radar, and to again provide an image of a moving target, a technique long used by the Navy to identify ships at sea.

As with TDOA ELINT networks, the area in which a network of MTI radars can precisely locate moving targets is limited by the area in which the coverage of all three radars overlap, and by the geometry of the radars relative to the targets within that area. In both cases, the network's requirement for three sensors within line-of-sight of the target reduces the range the network can see into contested air space from a standoff position. For example, when networked to precisely locate moving targets, three widely separated radars able by themselves to see 150 miles into contested air space might collectively cover an area roughly 50 miles deep.

For other classes of high value mobile targets, initial detections will usually be made by means other than ELINT, but tracking and targeting requirements will be similar. For example, a mobile ballistic missile is launched by a large transporter/erector/launcher (TEL). Such TELs are needed to launch weapons like the SCUD and other missiles, and even if destroyed only after their first use, their destruction could limit the ability of an opponent to expend his entire arsenal or missiles. The best way to detect a missile launch and roughly locate the launch point is to use two Defense Support Program (DSP) satellites to provide two widely separate bearings on the infrared plume associated with the missile launch. This cue can in turn be used to direct a radar to use the GMTI mode to see if any vehicles are fleeing the area, and/or to image the area of concern in search of a stationary TEL. Whether the TEL is found at the launch area or tracked to its hide site, the premium will again be on attacking it as soon as a targeting solution is possible. The more ambitious task of interdicting a missile TEL on its way to a launch point will depend on GMTI radar networks simultaneously capable of detection, identification, and precise tracking of moving targets.

In the distant term, many or all of these sensors might be deployed in space. For example, it appears that a space-based radar program to succeed Discoverer II is in the works. If successful, such a program would clearly be an ideal platform for persistent SAR imaging because a network of 24 satellites in low earth orbit would put one satellite overhead at all times. But with only one satellite overhead, this constellation could not provide precision MTI tracking or TDOA ELINT unless it exploited bistatic techniques using networks of receive-only UAVs as well. Even though such a network would still be limited by the line-of-sight of its UAVs, it would be a great improvement over current SAR/MTI networks because the UAVs would not need to carry radars. This would make it much easier to deploy them in an access-constrained environment because they could be made smaller and stealthier than systems like Global Hawk.

The promise of space-based radar is such that its development needs to be pursued, but for the next ten or fifteen years it will be necessary to deploy these sensor networks on manned fighter and/or bomber aircraft; penetrating UAVs; long endurance, standoff UAVs like Global Hawk; or manned widebody aircraft like the Air Force's Multimission Command and Control Aircraft (MC2A) or the Navy's Multimission Aircraft (MMA). These networks will be constrained by the power-aperture products of their radars, which will likely have maximum detection ranges against ground targets of 100-150 miles when deployed on large aircraft and 50 miles when deployed on fighters and medium-size UAVs. They will also be constrained by limits on the line-of-sight of those radars caused by terrain obstructions, which will vary depending on the altitude of the radar platform. And when networked together in order to do TDOA ELINT, or to precisely locate moving targets, the area in which both radar and ELINT networks can provide precise targeting will be further reduced by the need to have three rather than only one sensor within line-of-sight of the target.

There is of course a basic tension between these constraints and the capabilities of modern air defense systems like the SAM-10 and the SAM-12, which have engagement ranges against high flying, non-stealthy targets that may reach 250 miles, and which, at the other extreme, have some capability to shoot down even the stealthiest targets at ranges up to 40 miles.

Providing Persistent Sources of Precise, Time Critical Fires

Another set of issues associated with the general mobile target problem is the relationship between the sensor network and the time critical fires network. Though it has become common after Enduring Freedom to note that attacking mobile targets requires a network of sensor and weapon platforms linked by robust data links, less commonly noted is the strong mutual interactions between the capabilities of the sensor network and the requirements for the fires network. For example, a highly capable sensor network able to precisely locate potential targets will allow use of GPS-guided weapons that do not require a terminal seeker and carry relatively simple, inexpensive unitary or submunition payloads. On the other hand, a less capable sensor network that produces less precise geolocation

information will require use of weapons with terminal seekers or which deploy more expensive submunitions.

In addition, in highly contested air space protected by double digit SAMs, there are no simple choices regarding the means of time critical weapon delivery. First, no amount of stealth will protect an aircraft that must orbit targets within the range of GPS or laser-guided gravity bombs with ranges of at most 10-15 miles. Glide bombs can boost weapon range to about 40 miles, which may be far enough to protect stealth aircraft from a SAM-10, but in that case they must be carried internally. This is not a problem for the B-2, but internal carriage becomes a real constraint with aircraft like the F-22, whose weapon bays are small. Hence the small diameter bomb program, which is a GPS-guided glide bomb with a maximum range of 40 miles, a 250 lb. payload, and terminal seeker. At 40 miles range, the time-to-target for a glide bomb is at least 8 minutes.

Larger rocket-propelled standoff weapons can deliver the same payloads with much less time-to-target over the same distance as a glide bomb, but these weapons are too large for internal carriage by any stealth aircraft, while at the same time they do not provide enough standoff for non-stealthy aircraft to use them against targets defended by double digit SAMs. The HARM antiradiation missile is a special case in this category. It is faster than the other missiles, but carries a very small warhead. But like other air-launched rockets, it too is too large to fit internally on stealth fighters, and lacks the range to be used by non-stealthy aircraft against double digit SAMs.

Air-launched jet-propelled cruise missiles small enough to be carried externally by non-stealthy fighters can reach out to about 150-200 miles carrying 500 lb. warheads. But at those ranges, which are necessary if the launch platforms are not stealthy, the launch platform becomes totally dependent on offboard targeting, and flying subsonically at less than 10 miles a minute, the weapon takes at least 15-20 minutes to reach the target.

Provided the same offboard targeting, cruise or ballistic missiles can be launched from over the horizon by surface ships or submarines. Standard 21" diameter and 20' long launchers can carry ballistic missiles that come in variants with ranges from 100-300 miles and payloads varying from 1000 to 400 lbs., or cruise missiles that can carry a 1000 lb. payload to a maximum range of 1000 miles.

Significantly, in the case of the TBM launched from over the horizon, the time-to-target is significantly less than that for all stealthy and non-stealthy aircraft weapon delivery options, including even the case of glide bombs delivered by stealthy aircraft orbiting within range of their targets. Even more significant, the warning time provided the target by TBMs launched from over the horizon is less than the actual flight time of the missile. By comparison, the warning time provided the target by a weapon launched by an aircraft orbiting nearby will be greater than the actual time-of-flight of the weapon, because the establishment of the orbit will itself provide warning of imminent attack, unless those orbits are maintained on a permanent basis, which will often be infeasible when nearby bases are scarce.

Standoff Weapon Alternatives

	Propulsion	Range (miles)	Warhead	Unit Cost (\$,000s)
JASSM	Jet	200	1,000 lb Unitary	> 700
SLAM-ER	Jet	175	500 lb Unitary	500
AGM-142	Rocket	50	800 lb Unitary	1,020
AGM-130	Rocket	40	2000 lb Unitary	885
JSOW	Glide	40	145 BLU-97 CEM	300
			6 BLU-108 SFW	500
			1,000 lb Unitary/ Broach Penetrator	700
ATACMS	Rocket	200	400 lb Unitary/ 310 M-74 APAM	460
			8 BLU-108 SFW	660*
			4 LOCAAS	660*
Tactical Tomahawk	Jet	1000	1,000 lb Unitary/ 145 BLU-97 CEM	600

Attacking double-digit SAMs will require standoff weapons. Submarine-launched, standoff weapons are no more expensive than air-launched weapons.

- These prices are estimates based simply on adding the cost of the submunitions to the base ATACMS. They assume that P31 BLU-108 costs \$25,000 each and that LOCAAS will be \$50,000 each.

Finally, against double digit SAMs, there are no viable aircraft weapon options that use weapons costing less than \$300K, which is the cost of the cheapest JSOW glide bomb variant, which can be carried internally by the Navy and Air Force versions of the F-35, but not by F-22. More advanced versions of JSOW, as well as air-launched cruise missiles that can be delivered by non-stealthy aircraft, such as SLAM-ER and JASSM, all cost between \$500-1000K. If provided jamming and Wild Weasel escorts, non-stealthy aircraft might be able to deliver air-launched rockets such as AGM-130 or 142 against double digit SAMs, but these weapons also cost well more than \$500K, and the HARMS that would be expended to protect the launch platforms cost about \$300K apiece.

It is illuminating to compare the cost and performance of these weapons with Tactical Tomahawk and ATACMS, both of which are candidates for deployment on SSGN. Tactical Tomahawk has a maximum range of 1000 miles, but for our purposes here it is more germane to note that it flies at roughly the same less than 10 mile/minute speed as SLAM or JASSM. This means that an SSGN deployed near an enemy coastline

can put a Tomahawk on target as quickly as an aircraft orbiting near the same coastline can using SLAM or JASSM.

Current versions of ATACMS have a maximum range of about 200 miles and have true ground speeds of more than 20 miles/minute while flying greater than Mach 4 in a semi-ballistic trajectory. A variant of ATACMS with a 300 mile range is available for development that would substitute a carbon fiber motor casing for the current steel casing, allowing the increased range at little or no cost in reduced payload. Forward deployed SSGNs could put such weapons on target two to four times as quickly as any air breathing or glide weapon that must stand off at least 40 miles from its target. Also, ATACMS is probably the weapon of all those described least likely to be shot down by SAM-10s, with the possible exception of JASSM, and is definitely the weapon that, once launched, gives a mobile target the least amount of warning that it is being attacked. In fact, to give one pertinent example, it is likely that ATACMS is the only weapon of those listed where the time between initial detection by a SAM radar and impact is so short as to ensure that a mobile SAM battery can not break down and move in the interim. Current ATACMS costs vary according to the payload carried. The basic missile with either a unitary or APAM submunition payload costs \$460K.

The rapid over-the-horizon strike capability provided by systems like ATACMS is obviously limited by the location of its launch platform. If forced to stand off 250 miles, a platform carrying weapons with a 300 mile range will not be able to reach very deep into contested air space. Even deployed on a platform that can operate very close to the opponent, such as a nuclear submarine, missiles like ATACMS will still reach no further than 250-275 miles inland. In an access-constrained environment, this will be less of a constraint than one might assume given the alternatives.

For example, assuming assured access to tanking just outside the air space in question, bombers can fly several thousand miles into contested air space. But if bombers require fighter and/or jamming escort in order to penetrate hostile air space, then they can only penetrate as far as those escorts can reach. Furthermore, this constraint will get worse before it gets better when the Air Force substitutes the F-22 for the F-15C. One of the main advances of the F-22 over the F-15 is the F-22's supercruise capability, but when used as intended, this capability limits the F-22's unrefuelled radius to 300 miles or less, which roughly matches the current radius of action of the Navy's carrier-based F-18C. The F-15s and F-14s that are now being replaced have unrefuelled radii of about 500 and 600 miles respectively. Both the Air Force and Navy version of the F-35 will extend the range at which fighters can project air superiority into contested air space beyond 700 miles, but not until sometime in the next decade.

Another issue concerns offboard sensing support. The U.S. normally assumes that penetrating bombers and fighters must also be supported by AWACS and/or RC-135s, which limits the range of those penetrations to the line-of-sight range of those platforms from their orbits outside contested air space. If observed, this constraint limits penetrations to a radius of no more than 250 to 300 miles no matter what the range of the penetrating aircraft. Finally, manned aircraft operations in contested air space normally must be supported by combat search and

rescue forces, whose radius of operation is normally limited by the unrefuelled range of helicopters like the CH-53 or CH-60.

Given these constraints, one question concerns the real utility of a bomber's increased range compared to fighters in deep attack operations. If bombers need fighters to escort them, then they cannot conduct deep attack operations beyond the latter's range until the air defenses are destroyed, and if fighter escorts are not available because of the absence of local bases, than bombers that need escorts cannot penetrate at all unless sea-based fighter escorts are available. The B-2 can evade these constraints if planners are comfortable with using them in truly autonomous, deep operations, supported only by whatever space-based ELINT is available, and with no prospect of recovering the crew if an aircraft is shot down. That means that B-2s may be the only real source of true deep attack capability by a manned platform, and that is true only if military planners are comfortable with running risks that so far, they have been unwilling to run in the actual operations in which F-117 and the B-2 have been used.

But even in this case, B-2s will only really be effective against fixed targets because there will be no sensor network available to find, identify, track, and locate mobile targets. Until such networks can be put in space, they will depend upon air breathing platforms like U-2 and Global Hawk, which have even worse line-of-sight constraints against mobile ground targets than platforms like AWACS and Rivet Joint have against airborne fighter aircraft and emitting radars.

In short, the reality is that even though cruise missiles and perhaps B-2s have an ability to strike fixed targets deep inland, the U.S. military will have little operationally realistic capability to launch time critical strikes against mobile targets deeper than about 150-200 miles into contested air space regardless of the weapon/weapon platform combination that it chooses.

Of course range remains of fundamental importance in the future security environment. In this particular case, the value of extended range is that it can be translated into long endurance, a capability that could be very important to attacking mobile targets within the 150-200 mile deep band of contested air space where the U.S. military can extend its mobile target sensing networks in the near to mid term. Long endurance weapon platforms are one important means of exploiting persistent mobile target surveillance networks because they can easily maintain orbits near the areas being continuously surveilled. And obviously, the value of range for deep attacks against both fixed and mobile targets can be recovered if an opponent's air defenses can be rolled back. But because the most advanced of those air defenses will be mobile, the initial rollback operations will be limited to the 150-200 mile deep band described above.



BAT (8)



BLU-114 (160)



BLU-108 (8)



LOCASS (4)



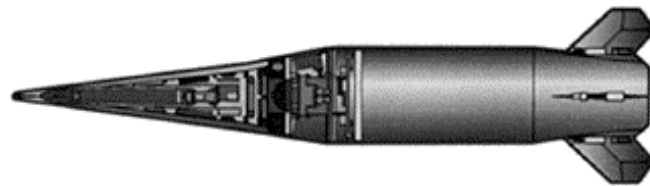
WAM (8)



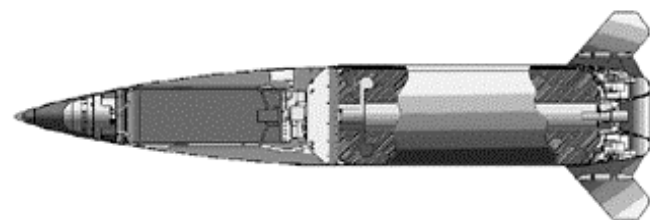
SADARM (24)/SMART (24)



Small Diameter Bomb



Penetrating Warhead



Unitary HE Warhead

Tactical ballistic missiles will be key members of the time critical strike networks needed to exploit persistent surveillance networks, and their warheads must be tailored to the needs of those surveillance networks and the targets they find. For example, the same ATACMS missile can be deployed with a unitary HE

warhead, a hardened penetrating warhead, and using a universal dispenser, the full range of dumb and smart submunitions in DOD's inventory.

Sensors and Payloads for Trident SSGNs

The previous two sections describe the dual challenges of dealing with access constraints and becoming better at finding and attacking mobile targets. These two challenges merge in the particular case of destroying double digit SAMs, which is why so much attention has been paid to that specific task. Meeting the demands of that task will require transformation, and the means chosen for that task will be an example of the kind of force demanded more generally by the new security environment.

To summarize the previous discussions, there will be three keys to accomplishing this transformation. First, sensor networks will need to be continuously deployed within line-of-sight of SAM operating areas that are able to locate radars quickly and with targeting quality precision by exploiting even brief radar emissions. Second, weapon platforms will need to be continuously deployed close to those radars so that once located, they can be quickly brought under attack, and the weapons used in those attacks must be fast enough as to provide insufficient warning once they are detected in flight for the radar to break down and move. Third, effective destruction of enemy air defenses will depend on the simultaneous deployment and use of weapons that threaten something the enemy values enough to need to defend.

That is because effective destruction of enemy air defenses will still depend on some degree of cooperation by the enemy. That is, if he refuses to use his radars altogether it will be very difficult to attack them and they will remain a threat-in-being. This is the bane of any small, silver bullet-like, precursor force that depends on a cooperative enemy for its effectiveness. If the leading edge, access enabling force is too small, and is focused narrowly on the air defense destruction mission, it will not pose a threat sufficient to force the opponent into using those air defenses, and if the opponent is not forced to use his defenses, they can not be attacked effectively. This vicious circle can best be broken if the leading edge force has the payload to threaten high value, fixed targets as well.

These three requirements are difficult enough by themselves, and they become even more difficult when one factors in the other constraints on access that are likely in future conflicts. Submarines are the only platforms that are essentially immune to those constraints, and SSGN brings to the submarine force the payload necessary to force an opponent to defend himself.

Submarines used in the strike role have two unique attributes. Certainly, like all naval platforms, they are immune to the political constraints on access that can limit land-based forces' use of bases near the opponent. But when used independently, they provide a means of bringing weapons within range of their targets prior to a conflict without alerting those targets that they are being held continuously at risk. And second, early in a conflict, they provide the only weapons platform that can operate with persistence and at close range amidst an opponent's access denial forces.

To give an example of the first unique attribute, after August 7, 1998, the day that al Qaeda destroyed the U.S. embassies in Nairobi and Dar es Salaam, the Clinton administration ordered the Navy to maintain two Los Angeles class attack

submarines on permanent station in the Arabian Sea.⁸ The purpose behind this assignment was threefold. First, sea-based cruise missiles proved to be the only means of striking deep into Afghanistan that could be deployed to the region without depending on the use of local bases. Second, cruise missiles could be placed on target within hours of the order to launch, whereas long range bombers launched from outside the region would take more than a day to arrive over target. And third, submarines were the only means of deploying cruise missiles without alerting the target to their presence.

Given these unique attributes, SSGN will have particular value for three reasons. First, prior to conflict, it is the ideal platform to deploy if one wants to hold a significant number of targets at risk without alerting the potential opponent. From such a posture, SSGN would be able to launch powerful surprise attacks against both fixed and mobile high value targets. Second, once a conflict had begun, SSGN would be the ideal platform for launching reactive strikes against high value, mobile targets that expose themselves when they move, emit, or fire a weapon, but which quickly disappear if not immediately struck, such as mobile SAMs. And third, in many cases, SSGN would perform both these roles in rapid sequence. It would be a major source of the first strikes against high value targets like Weapon of Mass Destruction (WMD) storage sites, and as a result it would be optimally located to strike quickly and decisively when the opponent uses his air defense and other access denial forces to defend those high value targets.

The biggest challenge facing the submarine force in preparing for these scenarios will be determining the proper mix of sensors, payloads, and connectivity to be deployed by SSGN. This challenge is complicated by the fact that sensor, payload, and connectivity requirements are strongly interconnected, and that they vary depending on the specific mobile target set being held at risk, on the level of access available to joint forces, and on the phase of the conflict. Finally, it is also important to plan both for the near and the far term.

SSGN Sensors

The most important question concerns sensors because that is where the most uncertainty lies. How will SSGN obtain targeting information for its weapons, and should it have an organic capability to do so? Given the need for an organic capability, and given that UAVs will provide that capability, what capabilities should those UAVs be given?

The first rule of thumb should be that SSGN needs an organic, overland targeting capability only for those scenarios in which it must operate alone, either to maximize surprise, or because of extreme access constraints, or both.

In the first scenario, if the goal is to deploy SSGN alone to hold targets at risk covertly, then there is a need for a system that can quickly check for the presence or absence of a set of relocatable targets that have already been detected and geolocated by national, space-based, imaging sensors with low revisit rates. The goal here is to exploit the ability, over time, of national sensors to maintain an inventory of the location of various targets of interest, but to minimize the latency measured in hours or even days inherent to that source of targeting

information. When used to support a strike where surprise is of the essence, the goal would be to inventory a set of pre-planned aimpoints without the opponent detecting the activity.

Here, the technical requirements would be for a very small UAV with sufficient speed and endurance to fly out no more than several hundred miles, image a series of locations along the way, and return to within line-of-sight of the SSGN, whereupon the images would be downloaded and the UAV would be discarded in the ocean. The mission would be entirely pre-planned, eliminating the need for a continuous data link to the UAV. The imaging sensor should be night capable but would not require very high resolution. There would be no requirement in this case for the UAV to itself geolocate targets, though if such a capability were desired it could be accomplished by adding a laser range finder to the payload. A simple UHF transponder would provide the necessary bandwidth for the line-of-sight links necessary to implement this concept. In the event of the need for an over-the-horizon, real time monitoring capability, line-of-sight relays could be established using two or more UAVs, at the expense of some reduction in covertness. In general, the UAV would be covert through some combination of small size, slow speed, and if necessary, stealth treatment. Such a concept would allow SSGN to launch surprise attacks at high value, relocatable targets with both low target location error and low latency.

In the second scenario, the goal is to deploy SSGN very close in an access-constrained environment so that it can launch time critical strikes against SAM engagement radars when they emit. Here, there is a need for a system that can look 150-200 miles deep and quickly identify and geolocate radars within that area of interest when they light up. The best way to do this is to data link three airborne UAVs carrying passive, broadband, RF receivers in order to form a TDOA/FDOA ELINT network. If the UAVs can fly at 15-20K feet they can obtain the needed detection ranges and still downlink to the SSGN using line-of-sight links.

In this role, SSGN would not need to deploy such a network for more than several weeks because success at rolling back the opposing air defenses would allow joint platforms like Global Hawk or U-2 to operate closer to the battlefield. UAV design for this role should place a premium on endurance, as the longer each UAV can stay aloft, the longer the network can be maintained, and the more coverage in either time or space can be maintained by a given supply of UAVs aboard the SSGN.

As a subset of this capability, a single UAV could be used to fly long baseline patrols normal to the direction of continuously emitting surveillance radars. The lone UAV would be able to provide somewhat less precise location of such radars by using multiple angle-of-arrival measurements against the same signal over many minutes of flight time.

In both cases, the UAVs, or some subset of them in the case of the TDOA network, would remain within line-of-sight of SSGN, downlinking the network output via UHF to either a mast antenna or a buoyant cable array. Also, in both cases, the targeting network would be resistant to jamming, because uplinks to the UAVs are not necessary. Also, because there are no uplinks to the UAVs, there is no danger

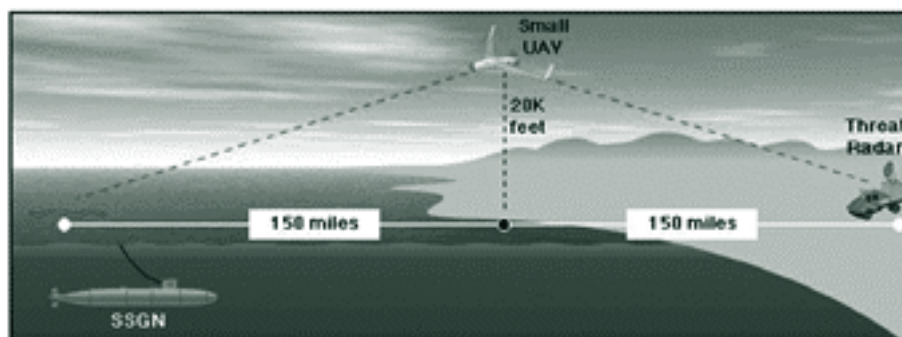
of SSGN betraying her position to opposing ELINT. Certainly, if desired in particular cases, uplinks would be feasible.

A TDOA ELINT network implemented by small UAVs will require more development than will a small UAV-based covert imaging capability, but there is a natural tradeoff that can be used to reduce the early demands on such a system. The key technical issue is going to be how quickly and accurately the network described can locate its targets. Using this method, DARPA has already demonstrated the capability in its AT3 program to locate radars within a circle of roughly 50 miles in diameter with location error of about 50 meters within a minute. Using the existing HARM Targeting System (HTS) pod, the Air Force is pursuing an upgrade that would implement a TDOA network among three airborne F-16 Wild Weasels that would provide even better accuracy and speed than AT3 has already demonstrated.

A small UAV-based TDOA network for SSGN would not need initially to perform as well as AT3 because 50 meters is far less target location error than is necessary to target ATACMS carrying existing smart sub-munitions like SADARM, Sensor-Fuzed Weapon, and BAT. These sub-munitions were designed for use against targets where the location error is in the low hundreds of meters. An added benefit of using more sophisticated sub-munitions is that they are like multiple, independently targeted, reentry vehicles (MIRVs) on nuclear ballistic missiles – they should lead to multiple vehicle kills per ATACMs shot. In the particular case of a SAM-10 battery, in which the radar, missile TEL, and command vehicles that form the battery are connected by short range, terrestrial data links, a single ATACMS might destroy a substantial portion of an entire battery.

On the other hand, if a small UAV-based TDOA network with capabilities approaching what DARPA has already demonstrated can be developed, it would support targeting ATACMS strikes using dumb, submunition payloads, in which case the price of each ATACMS shot would be kept very much at the low end of the scale for standoff weapons, including air-launched weapons.

Finally, in the more distant term, missile payloads with both a wide area search and an automatic target recognition capability like LOCAAS may prove feasible. If they do, this would enable truly deep missile attacks against emitters detected from space using single platform, multiple angle-of-arrival targeting techniques.



Submarines can detect radar emissions 300 miles away by deploying small UAVs .

The key addition to SSGN's weapon payload should be a tactical ballistic missile to complement Tomahawk. ATACMS will give SSGN the ability in an access-constrained environment to put ordnance on target faster than any other platform/weapon combination. This time critical strike capability will in turn play a key role in attacking high value mobile targets such as double digit SAM radars, as has been described at length above.

In turn, the combination of Tomahawk and ATACMS in a large payload submarine will be greater than the value of each used independently. For example, in the DEAD mission against double digit SAMs, it is important to note that such systems were originally designed by the Soviet Union against the nuclear cruise missile threat. If an opponent has double digit SAMs, they will provide his sole means of defending against cruise missile attack, because older fixed and mobile SAM systems have essentially no anti-cruise missile capability. Because SSGN greatly increases the size of the Tomahawk strikes that can be mounted early in a conflict, it makes it much more difficult for the opponent to pursue a threat-in-being strategy by withholding his most modern air defenses.

But if the opponent also faces the prospect of time critical, anti-radar strikes by ATACMS, he will not be able to operate his SAM batteries to anywhere near their maximum effectiveness against cruise missiles. Systems like SAM-10 were designed with the ability to elevate their surveillance and engagement radars some 100 feet atop telescoping columns in order to maximize detection and engagement ranges against low altitude cruise missiles. But when used in this way, the time to set up or break down the mobile radar goes from a few minutes to 90 minutes.

Even when used in the normal "look up," anti-aircraft mode, double digit SAMs with a break down and move time of only five minutes will not escape ATACMS attack if their first warning of that attack is the missile clearing the radar horizon incoming at Mach 4-6. If the break down time is extended to 90 minutes, SAM radars become completely vulnerable to time critical ATACMS strikes, as well as strikes launched by orbiting aircraft using weapons like JSOW or SLAM.

In addition to its use for striking mobile targets, ATACMS will give SSGN the potential for a hard or deeply buried target capability being developed by the Army for its land-based ATACMS. It will also give SSGN the ability to support its organic special forces teams with emergency direct fires when they are embarked.

SSGN As Part of a Joint Force?

What is the role, if any, of SSGN after opposing air defenses and other access denial forces have been rolled back, and when it is no longer operating alone or far forward of other forces? What unique contributions will its weapons continue to make when strike aircraft are available on a larger scale? Does it still need an organic targeting capability when it is operating as part of a joint force that includes surveillance assets such as U-2 or Global Hawk? If not, what will be the connectivity requirements if SSGN is to be plugged into a joint targeting network?

SSGN will continue to have a key role as access constraints are reduced because those constraints will not disappear all at once but in stages, and because even when there are no military constraints on access, extremely prompt fires will

remain crucial to destroying certain high value, time critical targets. In between scenarios where only SSGN can operate close in and where any platform can do so there is a large subset of cases where both orbiting aircraft and submarines will be able to operate close in, but surface platforms which operate from the sea will need to stand off 200 miles, and those which operate from fixed bases ashore will need to stand off 1000 miles.

This is the case because it will often be more difficult to destroy opposing submarines, and mobile, land-based antiship and land attack missiles than it will be to roll back ground-based air defenses. None of these systems need to emit RF signals in order to perform their mission as mobile SAM batteries do, and without such an ELINT cue, they are harder to find. But of course, once mobile air defenses have been rolled back, aircraft of all types will be able to operate much more freely in the littoral battlespace where all these threats are operating, and these aircraft will be able to "flood" the area with networks of both active and passive sensors. Combined with already deployed submarines, this air-undersea team will make searching for non-cooperative access denial forces a much more fruitful enterprise, and submarines including SSGN will continue to have a role both as sensor operators and as sources of prompt fires.

Access constraints aside, there will also always be a subset of very high value targets in any conflict that can be efficiently attacked only by very prompt fires. These might be leadership targets, targets associated with WMD storage or delivery, or some other asset that only intermittently exposes itself to attack.

In particular, the war against terrorism will likely continue to require strikes against targets like these where military constraints on access are relatively low, but where the political constraints on access will be very high. In cases such as these, both SSGN's strike capabilities and its ability to support much larger special forces operations will be important. And of course, as was demonstrated during Enduring Freedom, there is a powerful synergy between special forces on the ground wielding laser range finders integrated with GPS, and long endurance weapon platforms deploying GPS-guided weapons.

In all or most scenarios when SSGN is operating as part of a joint force it will no longer need an organic, overland targeting capability, but it will need sufficient connectivity to link into joint targeting networks. Providing this connectivity is both a technical and a cultural issue.

SSGN Connectivity to the Joint Force

The technical issues focus around bandwidth, and particularly over-the-horizon bandwidth to and from mobile users. The first and most important thing to understand about bandwidth for mobile users operating on data-laden battlefields is that there will never be enough if the supply of data is not filtered via information processing. This applies to all mobile users, not just so-called disadvantaged users such as submarines and combat aircraft. That is because the data generated by modern sensor networks is like rush hour highway traffic in modern cities; adding additional lanes simply causes commuters using less

convenient modes of transportation to shift to driving until the highway returns to gridlock.

Processing limits bandwidth requirements by extracting information out of the data stream. In theory, processing can be done anywhere between the sensor and the weapon in a sensor-shooter network. Today, it is largely performed at ground stations, aboard large surface ships, and aboard large aircraft. Though future sensor networks will do more processing at the sensor, the direct downlinks from most sensor networks will likely continue to require very high bandwidth because future sensor platforms will likely remain both weight and power limited.

This raises the question of whether and how much SSGN should be capable of receiving such direct downlinks from joint and national sensors and the answer in almost all cases should probably be no. Unlike the simple UAV-based, TDOA ELINT network described above, in which the time, frequency, and bearing of radar signals is the only data that needs to be transmitted, radar and optical imaging platforms like U-2 and Global Hawk download data at rates measured in 100s of megabits/second. In a properly designed network, the time gained by directly receiving this data compared to having it processed elsewhere and broadcast to the submarine as low bandwidth information should be minimal, and certainly should be much less than the decision time, which in a properly designed network will always be the major source of delay between sensor and shooter.

A more interesting question concerns whether and how submarines should receive the common operational picture generated by joint forces. It may be possible for submarines to host the full suite of fusion systems such as Tactical Exploitation System-Navy (TES-N), but in the likely case it is not, remote terminals for systems like TES-N are already being designed for experimental use by P-3s like today's Hairy Buffalo, and for future use by Multi-Mission Aircraft (MMA). The data rate required to maintain a continuously updated, common operational picture at a remote terminal will be no higher than 512 kb/sec, and will therefore not exceed what is available to submarines in scenarios where they have access to 1.5 mb/sec, line-of-sight, UHF links.

Another question is whether submarines should maintain such a common operational picture continuously when they are operating alone, or over the horizon from joint forces. Under these circumstances, the information broadcast to the submarine must come via SatCom, using either the 50 kb/sec links at UHF, or the 128-256 kb/sec links at SHF/EHF once the submarine HDR antenna is available. If higher data rates are needed, the HDR antenna will also be able to receive at greater than 1.5 mb/sec when Global Broadcast System spot beams are available. Thus, the bandwidth required may not always be available if the <256 kb/sec links that are continuously available to the submarine at UHF or EHF SatCom are not sufficient. But of course, when SSGN is operating alone because of extreme access constraints or the need to maximize stealth, there may be less need to maintain a continuously updated common operational picture, both because that picture will be changing less often when it is only being fed by space-based sensors, and because SSGN will be deploying its own sensors on small UAVs and UUVs.

Demonstrated Submarine Data Reception Rates

	SATCOM	Line-of-Sight
Dry Mast antenna	GBS 1.5 mb/sec SHF/EHF 128-256 kb/sec UHF 50 kb/sec	UHF 1.5 mb/sec Link 16 156 kb/sec
Wet Cable antenna	UHF 50 kb/sec	UHF 1.5 mb/sec Link 16 156 kb/sec

1. GBS – Global Broadcast System
2. Data rates for SATCOM downlinks using GBS/EHF/SHF assume spot beams.
3. Link 16 reception using a buoyant cable array has not been demonstrated but is no more challenging than UHF line-of-sight reception, which has been demonstrated.

Submarines can receive targeting information for their weapons with the connectivity they have today.

On the other hand, when submarines are operating as part of a joint force, they will almost always be within line-of-sight of large surveillance and C2 aircraft such as P-3, MMA, or the whole panoply of widebody Air Force platforms such as JSTARS, AWACS, RC-135, and in the future, MC2A and Smart Tanker. All of these airborne platforms will be relaying the common operational picture at either higher bandwidth UHF line-of-sight or via LINK 16, both of which the submarine can copy continuously using either mast antennas or a buoyant cable array.

Finally, the most important issue for the submarine force to be clear about is that the core connectivity requirement for SSGN in all scenarios is to continuously receive targeting messages for its weapons. Fortunately, this is a not a challenging requirement. SSGN's role as a source of close in, time critical fires by GPS-guided weapons make its core connectivity requirements akin to those of a combat aircraft being sent targeting messages while airborne. Furthermore, because SSGN can deploy weapons that are essentially immune to opposing air defenses, because SSGN can deploy those weapons continuously within range of their targets, and finally, because SSGN-launched weapons will impact their targets so quickly after launch, targeting messages ordering individual strikes should rarely require more than the provision of a GPS coordinate, a specific weapon payload, and a time on target.

The cultural issues associated with providing connectivity revolve around the tradeoffs of using dry versus wet antennas. During the Cold War, the submarine force often operated in areas where the need to deploy mast antennas would have compromised either its stealth or the performance of its acoustic sensors. Thus the reliance on one way broadcasts to towed cable or buoy antennas of very low bandwidth. After the Cold War, in much more permissive environments, it was initially difficult for the submarine force to adjust to continuous operations at periscope depth, but it has made this transition in how it operates faster and more completely than most realize.

Having made the internal adjustment to operating in more permissive environments, and having gained the resulting connectivity, the submarine force should aim to preserve this connectivity in the face of future opponent's who will have some ASW capability, unlike our post Cold War opponents to date.

Thus, for example, investing in stealthy buoyant cable arrays is not an admission of any sort that submarines face vulnerabilities when they operate at periscope depth today. Rather, it is a prudent investment that ensures if such vulnerabilities emerge in the future, they will have no effect on SSGN's connectivity. Such arrays can already support receipt of both UHF SatCom and UHF line-of-sight, and could be made to receive Link 16, while simultaneously meeting very stringent stealth requirements.

Investing in giving those arrays higher downlink data rates, as well as uplink capabilities, without compromising the submarine's non-acoustic stealth is an important insurance policy. For example, if a true peer competitor emerges, submarines and satellites may be the only platforms that can close with the enemy early in a conflict. In such an environment, the SatCom uplinks that U.S. forces now depend upon for over-the-horizon communication will likely be denied by an opponent that understands both their vulnerability to jamming, and the central role they now play in relaying targeting information from ground-based data fusion centers to weapon platforms. In this case, submarines may need to downlink data directly from satellite-based sensor networks and they will need the bandwidth to do it.

SSGN and UUVs

Large UUVs will not necessarily be needed by SSGN in the near term in its role as a source of time critical fires, but UUVs are a major downpayment toward a future where SSGN will play other roles, or where it will want to expand its capabilities as a strike platform.

For example, the deployment and operation of undersea surveillance systems such as Advanced Deployable System (ADS) and its successors will need to be done covertly, which will therefore require a large payload submarine that has the ability to unload large cargos while submerged. The same requirement will be generated if and when undersea communication grids are developed, whether to support ADS or for other purposes. These would allow submarines and other undersea vehicles to deploy covert undersea communication networks using some combination of fiber-optic cable for longer range links, and "phone booths" that allow submarines to use blue-green lasers or active acoustics to patch into the network when necessary.

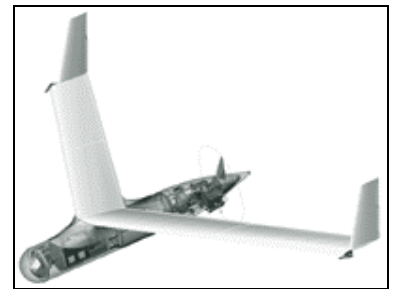
Large UUVs will also provide a means for the submarine to extend its reach or mask its location. UUVs could be used to launch UAVs from locations SSGNs couldn't reach or from which the launch of a UAV might compromise its location. UAVs could play the same role as the launch vehicle for smaller, short range weapons like those envisioned in the DARPA Net Fires concept. Such weapons would be particularly useful for fire support type missions where payload and range are less important than very low cost and extreme responsiveness. For example, a UUV could

free SSGN from the need to remain close in to serve as an emergency, on call source of fires by embarked SEAL teams. Several such UUVs might play the same role in support of small unit Marine Corps operations.

In all these cases, and in the many cases that cannot yet be imagined, the key capability provided to SSGN by UUVs is the ability both to remove payload from the submarine, and to replace it. The most likely near term use for UUVs is as a means of launching UAVs taken from the SSGN, and a means of replenishing the SSGN's supply of those UAVs while underway.



When SSGN is operating alone, either to hold targets at risk covertly, or because military access constraints are severe, small, inexpensive UAVs that can fly for days before being discarded will be ideal sources of imagery and ELINT.



Conclusions

Trident SSGNs will transform how the U.S. military projects power in an access-constrained environment. It will do this primarily by serving as a large payload source of very precise, prompt fires that can deploy with persistence very close to future opponents no matter how robust their access denial forces. No other existing or planned platform can provide this capability. The highest leverage targets for those fires will be very high value fixed targets, whose prompt destruction strikes directly at an opponent's vital interests, and the access denial forces that must expose themselves to defend those vital interests. In the near term, the most important access denial forces for SSGN to aim at are high end, mobile SAM batteries because their prompt destruction will both enable more effective operations against other, more difficult-to-find, mobile access denial forces, and in turn, enable access for much larger follow on forces that bring the mass needed to conclude the conflict in decisive fashion.

But as with all transformation, today's Trident SSGN program is only the beginning. In at least six areas, SSGN exploits technology where the pace of future gains will accelerate rather than decelerate. The returns on investment in these areas in the coming years will be great, and the consequences of their development and collective employment unpredictable.

For example, small UAV-based, sensing networks will likely grow in capability, giving submarines increasing organic, situational awareness, both ashore and at sea, and provide better target location accuracies. Standoff precision weapons, and particularly tactical ballistic missiles, will almost certainly both drop in cost and improve in capability as economies of scale in the production of such weapons are achieved for the first time. The same virtuous circle will apply to weapon payload development because smart submunitions are already coming down in cost while improving in capability.

SSGN will also lead to innovations in both the dense storage of weapons and sensor platforms like UAVs, and in the ability to tailor specific weapon and sensor payloads to specific tasks on board the submarine rather than in the factory. One of the first steps down this road should be the double stacking of missile payloads in Trident missile tubes, which in the current plan have only half their volume occupied by a single stack of Tomahawks.

As noted above, buoyant cable arrays have the potential to give submarines continuous, high bandwidth downlinks at depth and speed without compromising non-acoustic stealth, giving submarines access to a continuous, high fidelity picture of the joint battlespace. At the same time, SSGN will likely serve as the first platform for deploying undersea sensors and communication networks that will provide a common undersea operational picture.

UUVs will play a major role in the deployment and operation of these undersea sensor grids. When necessary, they will also play a role in preserving maximal SSGN stealth by deploying and sustaining UAV networks, or by launching short range weapons like DARPA Net Fires missiles. Finally, SSGN-based UUVs will probably be the first platforms to perform covert, undersea replenishment of deployed submarines on a routine basis.

Thus, during the second 20 years of the Trident submarine force's existence, it will give the submarine force and the Navy a potent new tool for enabling and exploiting access in the future security environment. As the value of that tool comes to be understood, and as its capabilities evolve in some of the ways described above, it will likely serve as the template for the next generation submarine force.

Endnotes

1. At about 500-600 km range, missile designers must start considering staging if they wish to preserve a reasonable payload. Though a two stage TBM is far from infeasible, it is a leap ahead in both technology and cost, and given the simplicity of the cruise missile alternative, the latter may be preferred.
2. For an excellent discussion of such TBMs and cruise missiles, from which this discussion of the vulnerability of fixed targets draws liberally, see John Stillion and David T. Orletsky, *Airbase Vulnerability to Conventional Cruise-Missile and Ballistic-Missile Attacks: Technology, Scenarios, and U.S. Air Force Responses* (Santa Monica, CA.: Project Air Force, RAND, 1999).
3. Again, in the long run, the U.S. Navy's recent decision to give its next surface combatant electric drive may prove fortuitous if this provides the power supply for terminal, directed energy defenses using solid state or free electron lasers if and when the latter become feasible. A surface ship is the perfect candidate for such a terminal defense because it is continuously moving, which means it can only be attacked by weapons with terminal seekers that a laser can burn. At the same time, it is among the largest and highest value moving targets, which means that unlike ground vehicles it has a large, organic supply of power which, on an electric drive ship, can be rapidly turned into electricity to power a laser.
4. These are all points made by Stillion and Orletsky, *Airbase Vulnerability*, p. 31.
5. For the U.S., today's ASW problem occurs primarily in shallow water, against submarines that are operating near their bases and waiting for their prey to come to them, and under circumstances in which the political tolerance for any ship losses is extremely low.
6. On the tactics pursued by the U.S. Navy in the '70 crisis, see Commander Edward P. Stafford, USN (Ret), "Tattletales and Bird Dogs," U.S. Naval Institute Proceedings, July 2001, pp. 71-74 and VADM Robert F. Dunn, USN (Ret)'s comments in "Comment and Discussion," Proceedings, pp. 20,24.
7. Bernard Brodie, *A Layman's Guide to Naval Strategy*, 1st Edition, 2nd Printing (Princeton, N.J.: Princeton University Press, 1942) pp. 88-89
8. See

The Future of the Trident Force

An M.I.T. Security Studies Program Conference
Royal Sonesta Hotel
Cambridge, MA

Day 1: November 7

- 7:30-8:15 Registration and Continental Breakfast
- 8:15-8:30 Welcome and Opening Remarks,
Owen Cote, Associate Director MIT/SSP
- 8:30-12:00 Morning Session
SSGNs and Time Critical Strike in the Near Term
- The Double Digit SAM Threat,
Owen Cote, MIT/SSP
- Targets, Surveillance and Targeting of High Value, Mobile, Time Critical
Cdr. Ron Carvalho, NAVAIR
- Sub-Launched Tactical Ballistic Missile Options,
Kirk Kirkpatrick, Lockheed Martin
- Quantifying The Value of Destroying Double Digit SAMs,
Jeff Cohen, Naval Undersea Warfare Center
- 12:00-1:30 Lunch
Speaker: Rear Admiral John Butler, USN
- 1:45-5:15 Afternoon Session: SSGN Missions in the More Distant Term
- SSGN Conversion Options,
Capt. Robert Hennegan, USN N77
- Expeditionary Sensor Grids,
Greg Duckworth, Forward Pass
- The Submarine As A Joint Force Enabler,
Randy Yates and Augie Billones, Team 2020
- A Submarine Road Map Beyond 2010,
Al Malchiodi, Electric Boat
- 5:30-6:30 Cocktails
- 6:30-9:00 Dinner
Speaker: Admiral Frank Bowman, USN

Day 2: November 8

- 9:00-12:00 Open Discussion/Debate of Issues
Moderator: Owen Cote, Associate Director MIT/SSP

Conference Participants

LCDR Emile Anderson
NWC

Charles Beers
Lockheed Martin

John Biederka
Electric Boat Corporation

August Billones
Lockheed Martin

Christian Bohmfalk
Inside the Navy

ADM Skip Bowman
Director, Naval Reactors

John Brandes
LMC-Perry Technologies

Duncan Brown
JHU/APL

Dave Burke
MIT

RADM John D. Butler
NAVSEA

Robert W. Button
RAND

CDR Ron Carvalho
USN

Dick Chapman
Rite-Solutions

Dr. Jeffrey Cohen
NUWC/NPT

Bryan Coles
Raytheon

Jim Conklin
PEOSUBS PMS450, NAVSEA

Owen R. Cote, Jr.
MIT Security Studies Program

Joseph C. Demko
Naval Reactors

Tim Devane
Northrop Grumman

Conrad Donahue
USN

Greg Duckworth
BBN Technologies

CDR James Foggo
USN

Jennie B. Fox
Lockheed Martin

Dennis Gallimore
Newport News Shipbuilding

C.H. (Bill) Gross
Lockheed Martin

Paul Hardy
JHU/APL

CDR Rusty Hathcock
NUWC

Captain Bob Hennegan
USN

RADM Jerry Holland (Ret.)
Holland Associates

Dan Howard
Lockheed Martin

C. J. Ihrig
Newport News Shipbuilding

Larry Johnson
SPA

Ernest Joyal
NAVSEA

Rod Kirkpatrick
Lockheed Martin

CDR Brad Kratovil
USN

Gary Letterman
Raytheon

Bill Lillie
Electric Boat Corporation

J. Woody Macias
Northrop Grumman

Col. David Mollahan
MIT Military Fellow

Al Malchiodi
Electric Boat

David N. Martin
Raytheon

Harry Mieras
Raytheon

John Muench
USN

Lt. Matt Mulcahy
USN

Jim Patton
Submarine Tactics and Technology Inc

John Pavlos
Electric Boat Corporation

Ron Pickul
NUWC

Frank L. Powell
Lockheed Martin

LCDR Mark A. Prokopius
USN

John Quigley
Systems Planning and Analysis

VADM J.Guy Reynolds (Ret.)

Edward Rishmany
NUWC

LCDR Derek J. Rollinson
NWC

Capt. Steve Ross

USN

Harvey Sapolsky
MIT Security Studies Program

David Scheerer
JHU/APL

Tom Schluckebier
MIT Military Fellow

Roger Sexauer
Electric Boat Corporation

Jennifer Sims
Johns Hopkins University

Nils Sjostrom
NUWC

David Sliwinski
MIT Military Fellow

RADM Gerald L. Talbot, Jr.
Commander, Submarine Group 10

Bradley Thayer
University of Minnesota

Mike Toner
President, Electric Boat Corporation

RADM Mike Tracey
Commander, Submarine Group 2

Capt. Brian Wegner
NAVSEA

Cindy Williams
MIT Security Studies Program

Ed Wright
SPA

Randy Yates
Northrop Grumman

The Security Studies Program (SSP) is a graduate level research and educational program based at the MIT Center for International Studies. The Program's primary task is educating the next generation of scholars and practitioners in international security policy making. Its teaching ties are mainly, but not exclusively, with the Political Science Department at MIT. However, the SSP faculty includes natural scientists and engineers as well as social scientists, and the Program is distinguished by its ability to integrated technical and political analyses in studies of international security issues. The SSP faculty, several of whom have had extensive government experience, frequently advise or comment on current policy problems. SSP supports the research work of graduate students, faculty and fellows, and sponsors seminars, conferences and publications to bring its teaching and research results to the attention of wider audiences.